STATE OF OHIO
Richard F. Celeste, Governor
DEPARTMENT OF NATURAL RESOURCES
Lt. Gov. Myrl H. Shoemaker, Director
DIVISION OF GEOLOGICAL SURVEY
Horace R. Collins, Chief

Report of Investigations No. 124

GEOLOGY AND FORMATION-WATER QUALITY OF THE "BIG INJUN" AND "MAXTON" SANDSTONES IN COSHOCTON, GUERNSEY, MUSKINGUM, AND SOUTHERN TUSCARAWAS COUNTIES, OHIO

by

Frank L. Majchszak

Columbus
1984

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GEOLOGY SERVES OHIO

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AUTHOR'S NOTE

Research on this project was commenced in September 1974 and formation-water samples were collected through August 1976. Research and manuscript preparation continued through October 1976, at which time a draft was submitted for publication. Between November 1976 and July 1980, little time was devoted to this project because of other project commitments. I left the Survey in July 1980 and since my departure only minor manuscript improvements and changes to accommodate pertinent recent geologic literature have been made. Thus certain statements in the text, such as those regarding shortages and increased prices for oil-field tubular goods, might seem odd in 1984. I have not attempted to gather or incorporate additional raw data, particularly additional borehole geophysical logs, that have become available in recent years.

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GEOLOGY AND FORMATION-WATER QUALITY OF THE "BIG INJUN" AND "MAXTON" SANDSTONES IN COSHOCTON, GUERNSEY, MUSKINGUM, AND SOUTHERN TUSCARAWAS COUNTIES, OHIO

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ABSTRACT

Subsurface mapping within the study area delineates the areal extent and thickness of two geologically and hydrologically distinct sandstone bodies that have been treated in the literature as though they were of the same geologic age and genetic origin. The drillers' term "Big Injun" sandstone is properly applied only to the western sandstone body, which can be traced to the outcrop of the Black Hand Sandstone Member of the Cuyahoga Formation (Lower Mississippian) using closely spaced borehole-geophysical-log control. The eastern sandstone body, the drillers' "Maxton," is correlated to the Sharon sandstone and conglomerate (lowermost Pennsylvanian).

Ultimate disposal of oil-field brine is a major environmental concern. This study came about partly as a result of suggestions that the "Big Injun" be used as a shallow disposal horizon for oil-field brines. The western sandstone body, because of its importance as a source of potable and brackish water, must not be used for this purpose. Certain parts of the area separating the eastern and western sandstone bodies proper may prove to be appropriate injection sites, but require additional research. On the basis of the results of this preliminary study, however, these localities do not appear to be particularly suitable for this purpose. That part of the eastern sandstone body in southern Guernsey County may prove to be suitable for brine injection; additional, perhaps even more suitable, sites for brine injection are likely to be present south of the study area in parts of Noble, Morgan, and possibly Washington Counties.

INTRODUCTION

The name "Big Injun" sandstone is not a formal stratigraphic name, but a drillers' term intended to designate the subsurface equivalent of the Black Hand Sandstone Member of the Cuyahoga Formation (Mississippian). The name Black Hand was applied by Hicks (1878, p. 216) to a sandstone and conglomerate unit which he described in the Black Hand Narrows of the Licking River in Hanover Township, Licking County, Ohio. Although he notes that the entire thickness of the Black Hand Member is not exposed in the Narrows, Hicks states that this locality is better known than the exposures "about Hanover" where the Black Hand "pudding stone" is best observed.

Another locality offering extensive exposures of Black Hand sandstone and conglomerate is the rugged and picturesque Hocking Hills area in western Hocking County. These outcrops, which so prominently display the geologic characteristics of the Black Hand Member, have received the attention of many geologists, who have advanced several theories on the origin of these rocks. In general, outcrop investigations either have been detailed geologic observations covering small geographic areas, or regional studies directed primarily at the delineation of facies relationships among the sandstone, shale, and conglomerate exposures.

Considerably less attention has been focused on the nature of these rocks as they disappear eastward beneath the cover of younger rocks. Although some oil and gas is produced from the drillers' "Big Injun" in southeastern and eastern Ohio, it is not a primary exploration target and thus has not been the object of detailed geologic investigation. Economic incentives related to oil and gas production in the recent past have generated an interest in the geology of this unit. Newly enacted regulations governing the storage and disposal of brine produced from oil and gas wells and sizable increases in the prices of oil-field tubular products have sparked this interest.

Ultimate disposal of produced brines is a major environmental concern. The most desirable oil-field-brine disposal method is reinjection into the formation from which the brine was produced. Injection into rock units above the producing zone almost invariably produces a deterioration in the water quality of the shallower horizon because water quality generally decreases as depth increases. Reinjection avoids this undesirable consequence and has the additional advantage of repressuring the producing reservoir.

However, in the case of the "Clinton" sandstone (Lower Silurian), the most frequently tested producing formation in the state, reinjection is not considered to be practical because of the relatively high cost of drilling "Clinton" wells and because this low-permeability reservoir accepts fluids reluctantly. As an alternative, some operators have suggested using the "Big Injun" as a disposal horizon because of its high porosity and permeability and because its formation waters become nonpotable owing to increased concentrations of dissolved salts as the unit is traced basinward (eastward).

Substantial increases in casing prices, resulting from temporary supply shortages, have escalated operating costs. This development has prompted some operators to question the necessity of setting 8⅝" surface casing through the "Big Injun" where it lies at depths in excess of 500 feet and is presumed to contain saline formation waters.

Consideration of possible solutions to casing-program and brine-disposal problems indicated a need for a better understanding of the geology of the drillers' "Big Injun" sandstone. This study was initiated to provide geologic information on this unit in east-central Ohio.

PURPOSE AND SCOPE

This investigation examines the subsurface geology of the sandstone units referred to as the "Big Injun," or simply "Injun," in Coshocton, Guernsey, Muskingum, and southern Tuscarawas Counties (fig. 1). Emphasis is placed on the distribution and thickness of the "Big Injun" and the areal variation in the chemical characteristics of its formation waters. Results of this study will help drillers, operators, and regulatory agencies estimate surface-casing requirements more accurately. Effective casing programs will assure adequate protection of potable and potentially treatable water supplies and prevent unexpected flows of formation water from impeding cable-tool drilling operations. Evaluation of the results of this report will aid in determining the suitability of these rocks for brine disposal.

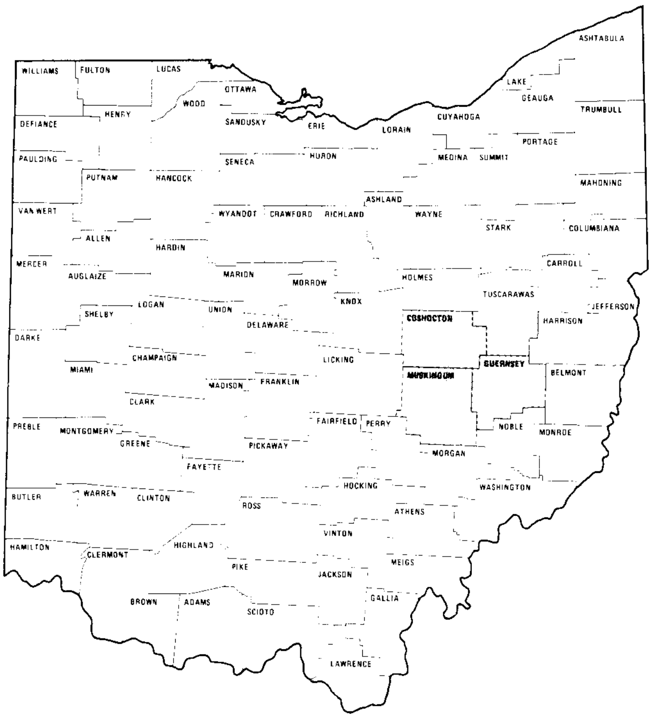


FIGURE 1.—Location of study area.

Within the study area, thousands of oil and gas wells have been drilled through the "Big Injun" horizon in quest of petroleum resources produced chiefly from the "Clinton" and from the Berea Sandstone (Lower Mississippian). Drillers' logs, which record the depths and thicknesses of rock units, differ greatly in quality and accuracy and require interpretation. Prior to the introduction of borehole geophysical logs, all subsurface research for which sample control was not available was based of necessity on information from drillers' logs. The diversification and refinement of borehole-geophysical-logging techniques have substantially increased the amount, type, and value of subsurface information and have served to improve and standardize data quality.

The "Big Injun" horizon has been logged in a sufficiently large number of wells in the study area to make it practical to restrict the current investigation to borehole-geophysical-log control interpreted with the aid of sparse sample suites on file with the Division of Geological Survey. Formation-water information is limited to samples collected or obtained by the author and analyzed by the staff of the Geochemistry Laboratory of the Division of Geological Survey.

ACKNOWLEDGMENTS

The author thanks the personnel of the Division of Oil and Gas for their advice and assistance in the initial phases of the field investigations. Formation-water samples were analyzed by the staff of the Geochemistry Laboratory of the Division of Geological Survey. Especially appreciated are the efforts of Norman F. Knapp, who reanalyzed several sets of samples acquired in the early stages of this research when discrepancies in the original analyses were discovered. Finally, the excellent cooperation of the operators and drillers who participated in the formation-water sampling program is gratefully acknowledged.

GENERAL GEOLOGY

GEOLOGIC SETTING

The area of investigation lies almost entirely within the Unglaciated Appalachian Plateaus physiographic province except for small parts of westernmost Coshocton and Muskingum Counties, which lie on the Glaciated Appalachian Plateaus. Within the study area, rocks of Mississippian and Pennsylvanian age are exposed at the surface (fig. 2) or are covered by a veneer of soil or alluvial materials. Regional dip and subsequent erosion have produced a broad arcuate band of Mississippian rock exposures which trend north-south through central Ohio. This outcrop band lies just west of Muskingum and Coshocton Counties. Mississippian outcrops extend eastward into the study area in the well-developed drainage systems of the Licking, Muskingum, and Walhonding Rivers.

Structurally, the study area is situated on the western flank of the Appalachian Basin. The rocks are nearly flat lying. With local exceptions of small magnitude, the Mississippian formations dip to the southeast at approximately 20 to 30 feet per mile. The only major exception to the homoclinal southeasterly dip is a positive structural feature of moderate relief known as the Cambridge Arch. This structure trends north-northwest through the study area and can be identified readily on the structure maps (pls. 4, 5) in this report. The subsurface expression of the Cambridge Arch and the adjacent Parkersburg-Lorain Syncline will be discussed later.

MISSISSIPPIAN AND BASAL PENNSYLVANIAN UNITS

The uppermost part of the Mississippian System is absent in Ohio because of nondeposition or erosion represented by the Mississippian-Pennsylvanian unconformity. In general, Ohio's Mississippian section (fig. 3) consists of a sandstone-siltstone-shale sequence which, in some parts of southeastern Ohio, is capped by a carbonate unit, the Maxville Limestone.

The oldest Mississippian unit in Ohio is the Bedford Shale, which includes the "Second Berea" sandstone and the Cussewago Sandstone Member. The Berea Sandstone, which is the oldest rock unit considered in this report, is the most widespread and readily identifiable rock unit of

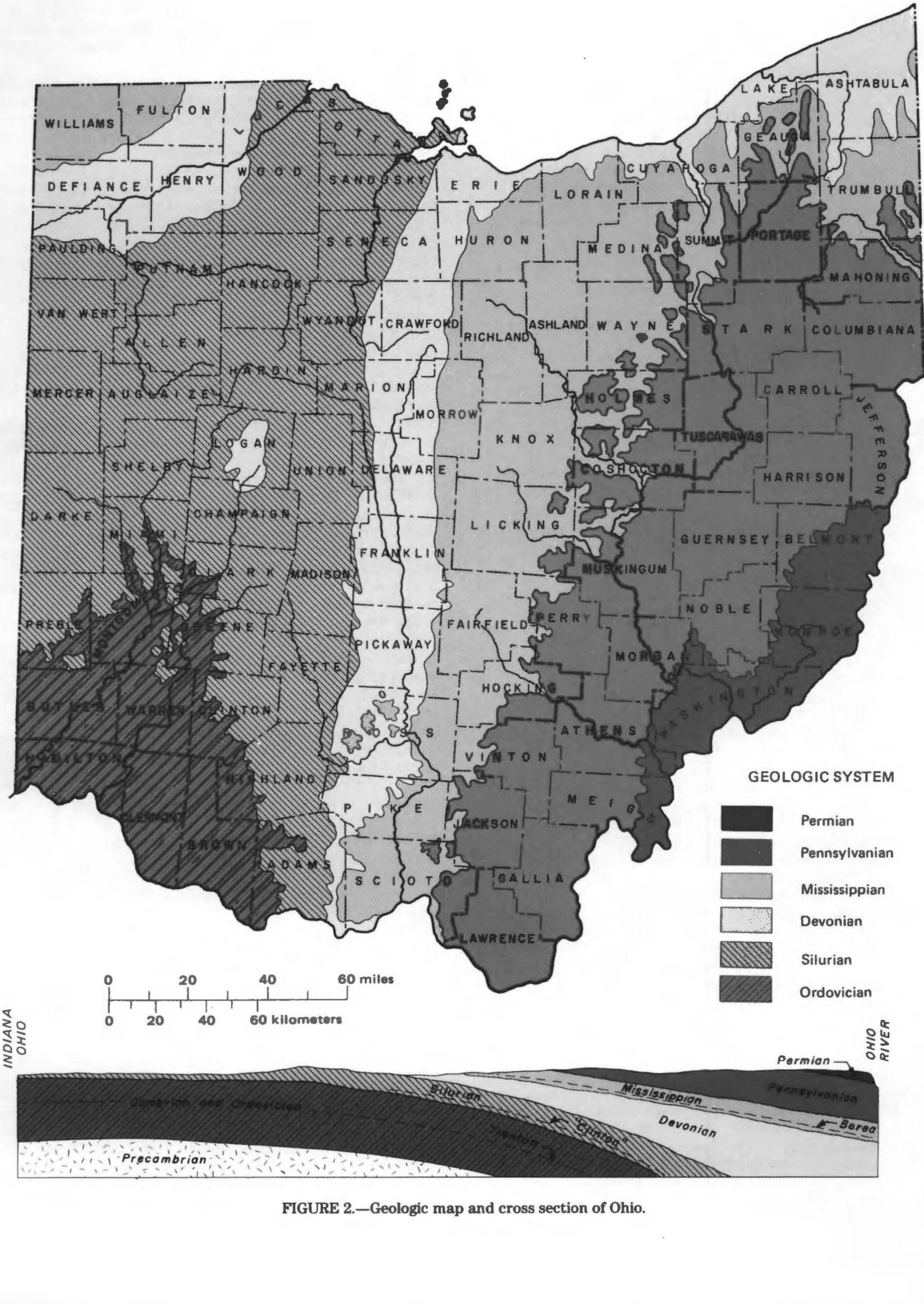


FIGURE 2.—Geologic map and cross section of Ohio.

SYSTEM	GROUP	FORMATION	PRINCIPAL MEMBERS OR BEDS	DRILLERS' OR INFORMAL NAMES
PENNSYLVANIAN	Pottsville		Homewood sandstone	Macksburg 700
			U. Mercer sandstone	Germantown
			L. Mercer coal	No. 3 coal
			L. Mercer sandstone	Schram
			Massillon sandstone	Salt
			Quakertown coal	No. 2 coal
			Sciotoville sandstone	Brill
			Sharon coal	No. 1 coal
			Sharon sandstone, conglomerate	Maxton
MISSISSIPPIAN		Maxville Limestone		Jingle Rock
		Logan Formation	Vinton Sandstone Allensville Conglomerate Byer Sandstone Berne Conglomerate	Keener
		Cuyahoga Formation	Black Hand Sandstone	Big Injun
			Portsmouth Shale	Squaw
			Buena Vista Sandstone	Weir
			Henley Shale	Hamden
		Sunbury Shale		Coffee shale
		Berea Sandstone		1st Berea
		Bedford Shale	Cussewago Sandstone	2nd Berea
DEVONIAN		Ohio Shale	Cleveland Shale	Little Cinnamon
			Chagrin Shale	Gordon
			Huron Shale	Big Cinnamon

FIGURE 3.—Generalized rock column of Upper Devonian through basal Pennsylvanian rocks in Ohio.

Mississippian age in the study area. According to Pepper, de Witt, and Demarest (1954), the Berea within the study area ranges in thickness from less than 10 feet to slightly over 100 feet. The Sunbury Shale, known to drillers as the "Coffee shale" or "the brown above the Berea," overlies the Berea. The Sunbury has a distinctive highly radioactive gamma ray log character, which aids in the identification of the Berea Sandstone in areas where the latter is thin and silty. Overlying the Sunbury Shale is the Cuyahoga Formation, which consists of the Henley Shale Member (containing the "Hamden" sandstone), Buena Vista Sandstone Member ("Weir"), Portsmouth Shale Member (containing the "Squaw" sandstone), and Black Hand Sandstone Member ("Big Injun"). Within the study area, neither the "Weir" nor the "Hamden" is present in the subsurface as a mappable unit.

"Squaw" sandstone is a drillers' term applied to the lower part of the "Big Injun" sandstone where it is separated from the main sandstone body by shale (Portsmouth Shale Member). The term is used occasionally in central Coshocton and Muskingum Counties. Subsurface investigation within the study area indicates that the upper and lower "Big Injun" sandstones are genetically related. Consequently, the "Squaw" is combined with the "Big Injun" and treated as a single mapping unit in this report.

Although some sandstone and siltstone stringers occur in the stratigraphic interval between the "Big Injun" sandstone and the Berea Sandstone, none within the study area are thick or persistent. For the present investigation, therefore, the rocks from the base of the "Big Injun" to the top of the Sunbury Shale are regarded as undifferentiated Cuyahoga Formation.

The "Big Injun" mapping unit, which undergoes rapid facies changes, is primarily a conglomeratic sandstone that commonly includes interbedded siltstones and shales. In a few localities, it is separated with difficulty from overlying units which exhibit similar borehole-geophysical-log characteristics.

The Logan Formation, which consists of the Berne Conglomerate, Byer Sandstone, Allensville Conglomerate ("Keener"), and Vinton Sandstone Members, overlies the Cuyahoga Formation. Like the Cuyahoga Formation, the Logan consists of interbedded shale, siltstone, sandstone, and conglomerate. In general, Logan sandstones are not as "clean" (porous and permeable) or as thick as the "Big Injun." In the central and eastern parts of the study area, pre-Pennsylvanian erosion has removed much or all of the Logan Formation.

The youngest Mississippian rock unit in Ohio is the Maxville Limestone. Scatterday (1963) considered the Maxville to be late Meramecian-early Chesterian in age on the basis of stratigraphy and conodont faunas. Uttley (1974) correlated the Maxville in Ohio with carbonate units in other parts of the Appalachian Basin. Uttley (p. 149) discussed the compound nature of the pre-Pennsylvanian erosional surface recognized by earlier workers and showed in cross section (p. 150) several intra-Mississippian erosional surfaces of low relief. By contrast, the post-Waverly or systemic unconformity—the interregional unconformity between the Kaskaskia and Absaroka sequences of the North American craton described by Sloss (1963)—locally exhibits considerable relief.

The youngest rock unit considered in the present investigation is the basal Pennsylvanian Sharon sandstone and conglomerate (the drillers' "Maxton"), which is the lowermost unit of the Pottsville Group. Younger Pottsville units include sandstone, shale, and coal beds. The Sharon clastics are thickest in what are interpreted to be paleotopographic lows developed on a pre-Pennsylvanian surface. Younger Pennsylvanian units overlie what are interpreted to be paleotopographic highs formed by the more resistant Mississippian rocks. According to Uttley (1974, p. 151-154), who cites evidence offered by previous investigators, erosion of Mississippian rocks and deposition of Pottsville sediments were contemporaneous processes at many localities. Where the Maxville Limestone is not present, the sandstones and shales of Pennsylvanian age below the lowermost coal are not easily distinguished in the subsurface from Mississippian clastics.

PREVIOUS WORK

Impressed by the beauty of the stone quarried at Waverly, in Pike County, Ohio, Briggs (1838, p. 79-80) proposed the name "Waverley sandstone series" for the rocks occurring between the "argillaceous slaty rock, or shale stratum" (Ohio Shale) and the "Conglomerate." According to Hyde (1953), the conglomerate Briggs referred to in Scioto and Jackson Counties was the "basal Coal Measures Conglomerate" (Sharon). In Fairfield and Hocking Counties, however, Briggs probably was referring in large part to the Black Hand conglomerate. Although the upper limit of Briggs' "Waverley series" was imprecisely defined, the name "Waverly" came to be widely accepted as a group name to include all Mississippian rocks in Ohio except the Maxville Limestone.

"Cuyahoga Shale" was the name used by Newberry (1870, p. 21) to designate the uppermost member of the "Waverly Group" in northern Ohio. Hicks (1878) devised a classification of the "Waverly Group" of central Ohio utilizing geographic names for the formations. As Orton (1888, p. 37-42) realized and Herrick (1891, p. 35-40) demonstrated, Newberry's northern Ohio Waverly section was abnormal and incomplete and represented only the lower part of the Waverly of central and southern Ohio. However, the name Cuyahoga persisted as a formation name until its definition ultimately was expanded to include rock units up to and including the Black Hand sandstone and conglomerate.

Prosser (1901) reviewed the development of the Waverly nomenclature and refined the classification scheme by restoring the geographical name which belonged to each formation by right of priority. Prosser elevated the Black Hand to formation rank and included in it what are now known as the Berne, Byer, and Allensville Members of the Logan Formation. Hyde (1915, p. 655-682 and 757-779) briefly outlined some of the correlation problems encountered by earlier investigators and advanced his own classification scheme for the "Waverly Group" of central and southern Ohio. Hyde used the concept of facies change extensively to explain the lateral variation in lithology observed along the outcrop. He defined five facies of the Cuyahoga Formation in his study area. The facies names, applied to the formation members at various localities, were presented in tabular form in order to facilitate their correlation. Holden (1942) modified Hyde's classification of the Waverly and extended the facies concept northward to include the entire outcrop band of Mississippian rocks. Holden illustrated the geographical extent of seven Cuyahoga-Formation facies and three Logan-Formation facies. Following an alternative suggested by Hyde (1915, p. 677, 678), Holden placed the Berne Member at the base of the Logan Formation. Hyde's 1953 report is a comprehensive presentation of his detailed studies of Mississippian stratigraphy and includes a synopsis of the development of the Waverly nomenclature. In recent years Bork and Malcuit (1979) have studied the Cuyahoga and Logan Formations in outcrop in central Ohio to determine their paleoenvironments.

Geologists who have studied the rock units of the Cuyahoga Formation in detail gain an immediate appreciation for the complex stratigraphic problems posed by these rocks. For example, Crombie (1952, p. 19) studied the Toboso and Granville facies in eastern Licking County and concluded:

> . . . the Toboso facies has a very complex history of submergence and deposition, emergence and erosion, reworking by submarine currents, and possibly a variation in the source area during deposition. [The facts] also lead to the belief that the Toboso facies is principally a submarine delta deposit which became subject to reworking by strong submarine currents, and aerial erosion due to local variations of sea level.

Although the outcrops of the Black Hand have provided the subject matter for numerous investigations, relatively little research has been conducted on its subsurface equivalent, the "Big Injun." Lamborn (1934, p. 259-262) briefly discussed the extent of two areas of well-developed "Big Injun" sandstone which are separated by an area of thin sandstone and shale. The only detailed investigation of the "Big Injun" is by Ver Steeg (1947). The greater part of his paper, however, is concerned with surface stratigraphy,

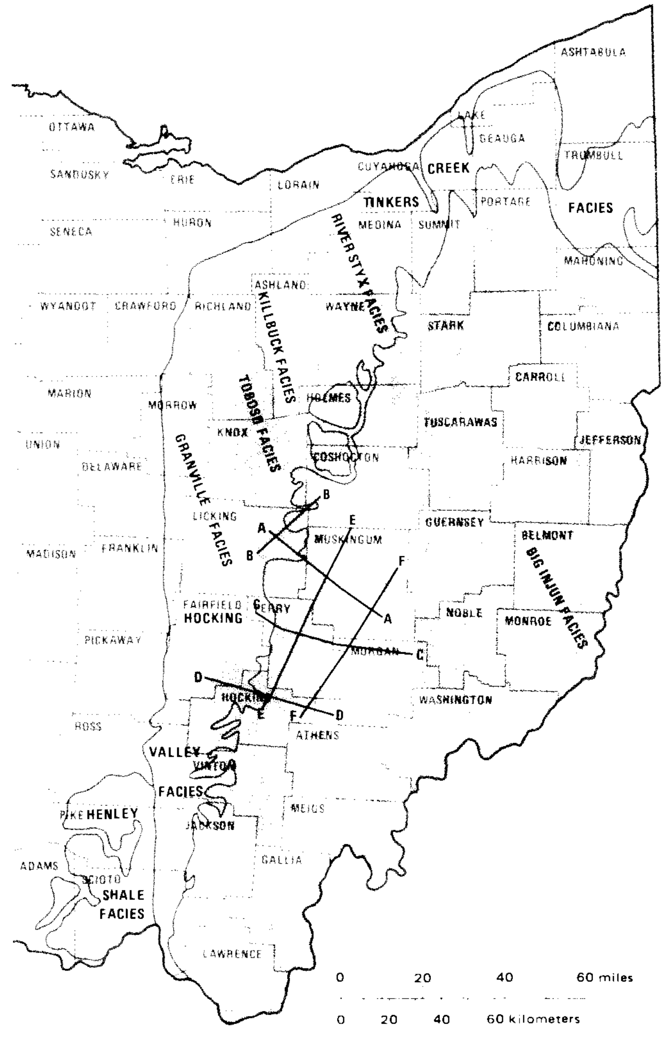


FIGURE 4.—Ver Steeg's map of his area of investigation and lines of cross section, including line of outcrop (screened line), outcrop-facies terminology, and distribution of the "Big Injun facies (modified from Ver Steeg, 1947, fig. 3). Pattern indicates area of conglomerate facies.

and most of the conclusions regarding the age of the rocks, mode of deposition, probable source area, etc., are based on outcrop observations.

Closely following previous investigators, especially Holden (1942), Ver Steeg (1947) discussed the facies relationships of the Black Hand along the outcrop. In the subsurface part of his investigation, which was based on oil- and gas-well drillers' logs, Ver Steeg mapped an extensive sandstone body in eastern Ohio which he called the "Big Injun Facies." Using "stick" cross sections, Ver Steeg correlated the "Big Injun" with the Black Hand sandstone of the western outcrop area. He also considered the "Big Injun Facies" to be equivalent to the "Big Injun" producing horizon of northern West Virginia. Figure 4 illustrates Ver Steeg's study area, the facies terminology he applied to the Black Hand outcrops, and the distribution of his "Big Injun Facies." Figure 5 is a reproduction of Ver Steeg's isopach map of the Black Hand Member. Ver Steeg's conclusions regarding the Black Hand and its subsurface equivalent, the "Big Injun," are stated in the summary of his paper (p. 726-727):

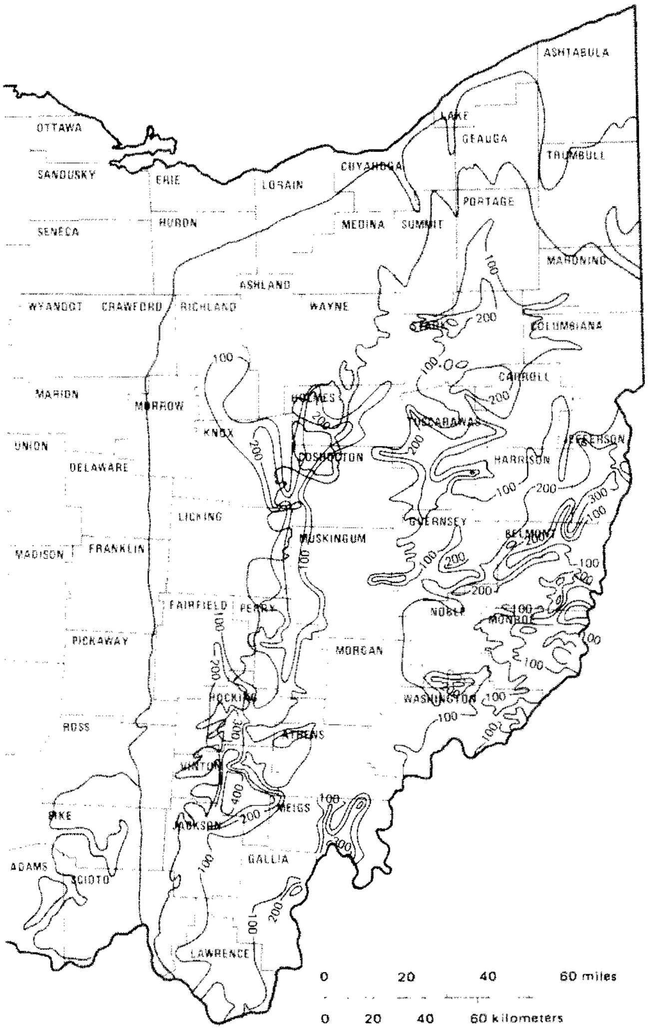


FIGURE 5.—Ver Steeg's isopach map of the Black Hand Member of the Cuyahoga Formation (modified from Ver Steeg, 1947, fig. 5). Contour interval 100 feet. Screened line is line of outcrop.

The Black Hand member varies so much in composition within short distances that it is difficult to trace. When traced horizontally from the conglomerate masses, the beds thin abruptly, contain more shale, and the sandstones are finer-grained and do not exhibit strong cross-bedding and evidence of scouring action. The conditions under which the Black Hand member accumulated were variable such as those that prevail along a shore line where finer muds and sands were deposited in lagoons or quiet deeper waters offshore, or in beaches, bars, or deltas where strong currents prevailed.

The facies are so distributed as to indicate that thick elongate masses of sandstone and conglomerate extend in a slightly west of north direction. They are marine, and the dip of the true bedding planes (3°-15°) suggests deposition in shallow water by rather strong currents with scouring action. All the evidence indicates that the currents came from the south.

It is probable that the Black Hand member was laid down in a shallow interior sea, in which beaches, bars, and deltas were developed. The presence of quartz pebbles from half an inch to as much as 2 inches in length in the conglomeratic facies, although not fatal to the delta theory, is not in harmony with observations which appear to indicate that finer sediments usually prevail in deltas.

The quartz pebbles are well rounded suggesting that they have been reworked several times. They were probably carried by waves and currents from their original site which was to the north or northeast and later reworked and shifted westward to produce bars, spits, beaches, and deltas. What appears to be a bar or offshore beach was built on the west side of the area.

The variable thickness and irregular contour of the top of the Black Hand member suggest an unconformity with the Berne conglomerate member at the base of the Logan formation.

The Black Hand member originally covered a larger area; a large part of the Waverly series was removed by erosion at the close of the Mississippian period.

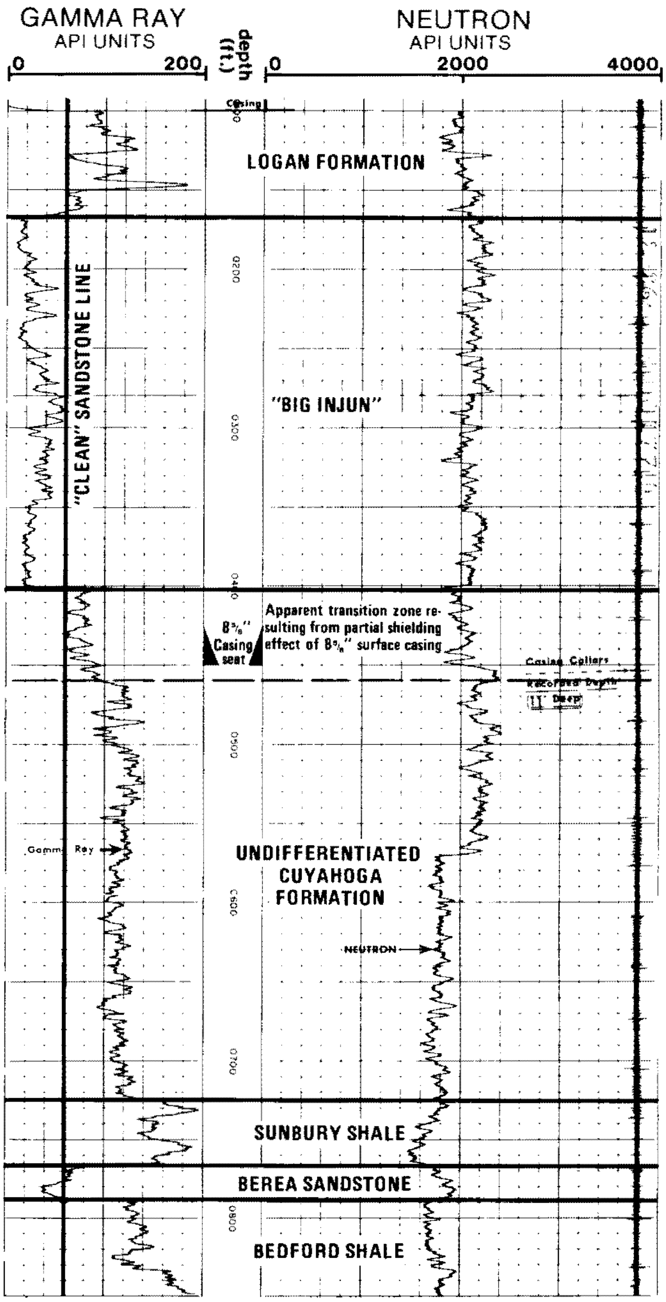


FIGURE 6.—Thickness and log character of the "Big Injun" sandstone in the Hunting #1-A Spittler well (permit no. 2796) in Hanover Township, Licking County. Well is located in the vicinity of Black Hand Narrows, which is the type locality for the Black Hand Sandstone Member.

Although Ver Steeg does not demonstrate a mechanism for interaction between the coarse clastics of the outcrop area and the areas of well-developed sandstone and conglomerate in the subsurface of eastern and southeastern Ohio, his use of the term "Big Injun Facies" clearly implies that the two areas are genetically related. Swick (1956, p. 19) made a similar implication:

> Subsurface studies indicate that the conglomerate facies of the Black Hand consists of lobes of a larger conglomerate mass to the eastward ("Big Injun" sand), and that the Granville shale facies is an accumulation of finer sediments between the lobes.

METHODS OF INVESTIGATION

BOREHOLE-GEOPHYSICAL-LOG INTERPRETATION

The lower contact of the Black Hand Member is not exposed at the type locality in Hanover Township, Licking County. Outcrop descriptions of the Black Hand Narrows refer only to the upper 100 feet of the member, whereas drillers' records of oil and gas wells in this area indicate a thickness of 250-300 feet for the "Big Injun" sandstone. The accuracy of the drillers' logs is supported by borehole geophysical logs of wells located less than a mile from the type locality. The borehole geophysical log of the upper part of the Hunting Oil Co. #1-A Spittler well, reproduced here as figure 6, illustrates the total thickness of the Black Hand Sandstone Member in the vicinity of its type locality. The top of the "Big Injun" in the #1-A Spittler well is correlated to the top of the Black Hand Sandstone Member at the type locality with the aid of nearby drillers' logs and surrounding borehole-geophysical-log control. Additional logs in Hanover Township allowed tracing of the "Big Injun" eastward into the study area to the National Associated Petroleum Co. #1 Mattingly well in Licking Township, Muskingum County (fig. 7). From this reference point, three north-south and two east-west stratigraphic cross sections (pl. 1) were constructed to provide a correlation network for the study area.

All borehole geophysical logs of wells within the area of investigation on file with the Division of Geological Survey at the time of this study (see Author's note, p. iii) were examined. Many operators in Ohio log only selected intervals of the borehole, or sometimes only the producing horizon in development wells, as a means of minimizing completion expenditures. In many cases, the Berea Sandstone is the only uphole unit logged. Each well which had at least a part of the "Big Injun" interval logged was used as a control point.

All pertinent information obtained from examination of borehole geophysical logs, available sample descriptions, and drillers' logs was tabulated. Landowner and operator names, location and elevation data, logging company, type and scale of logs, uphole casing points, number of casing strings, and any unusual log characteristics were noted for each well. Depths to water-producing horizons (derived from drillers' logs) also were recorded as a guide to the selection of water-sampling localities and as a correlation aid. Only the well location and identification, reference elevation, and unit depths are listed in the Appendix of this report.

The top of the Berea Sandstone, which was easily identified on the borehole geophysical logs, was used as a stratigraphic datum. The upper and lower contacts of the "Big Injun" generally were more difficult to establish. In some areas of western Muskingum and western Coshocton Counties the uppermost "Big Injun" was separated with difficulty from what is considered to be the subsurface equivalent of the Byer Sandstone Member of the Logan Formation. Differentiation of the two units in many wells was facilitated by the presence of a highly radioactive log "kick" caused by an unidentified lithology. Log kicks of this nature commonly represent brown or black organic shales, but no such shales are included in outcrop descriptions or mentioned on drillers' logs.

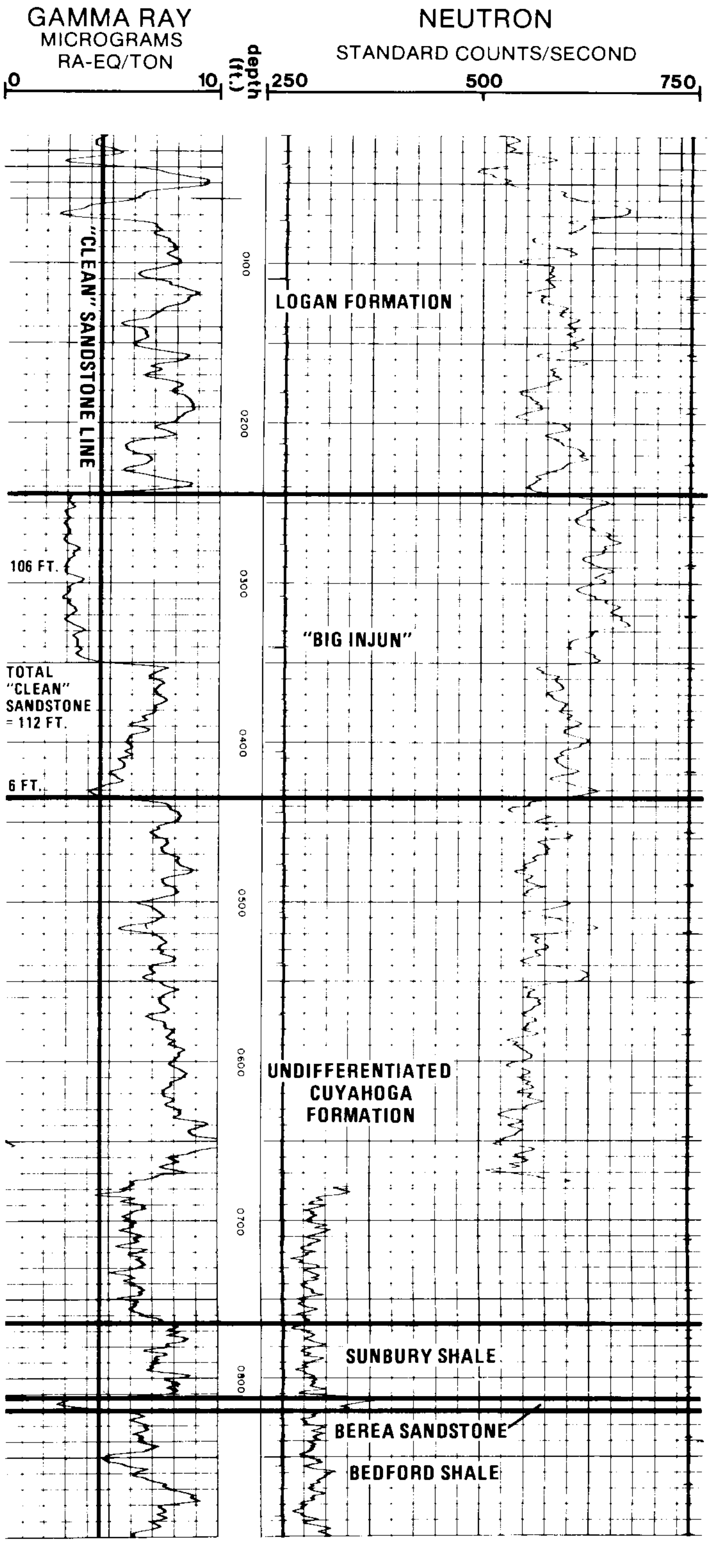
The thickness of the Berne Conglomerate Member, the basal unit of the Logan Formation, in the study area is not known. On the outcrop, the Berne generally is less than 10 feet thick and its lithology more closely resembles that of the Black Hand Member than that of the overlying Byer Member (Swick, 1956). Therefore, if the Berne persists in the subsurface, it most likely would be included in the "Big Injun" mapping unit. Alternatively, the Berne Member may be represented by the log kick separating the "Big Injun" from the subsurface equivalent of the Byer Sandstone Member.

Identifying the lower contact of the "Big Injun" presented the greater difficulty. Where the "Big Injun" is approximately the same thickness as at the type locality of the Black Hand, the lower contact generally is sharp and easy to recognize. As sandstone thickness diminishes, however, the contact in many places becomes gradational. Silty sandstone stringers separate from the main sandstone body are common within the stratigraphic interval occupied by the "Big Injun." In much of the central region of the study area only the upper third or less of the "normal" "Big Injun" interval is a sandstone. The remainder of the interval is a shale or silty shale which appears to be in facies relationship with the sandstone. In such cases the base of the "Big Injun" was picked at the lowermost sandstone stringer or shale equivalent which appeared to be genetically related to the "Big Injun," as interpreted from the borehole geophysical log.

A paucity of sample control made it necessary to rely on borehole geophysical logs for lithologic interpretation. Within the study area, the "Big Injun" interval nearly always is logged through at least one string of casing, so that compensated neutron and density logs are unavailable for lithology determination by cross-plotting techniques. In fact, in many cases only a gamma ray log is run through the "Big Injun" interval. Examination of sample suites of wells logged by borehole geophysical methods demonstrated the feasibility of using gamma ray log response to identify the amount of "clean" (porous and permeable) "Big Injun" sandstone.

The gamma ray log measures the natural radioactivity of rocks. In sedimentary formations free of radioactive constituents, the gamma ray response normally is a shale indicator. In general, shales have high gamma ray readings while shale-free sandstones and carbonates have low readings. Figure 7 correlates the gamma ray response in the National Associated Petroleum Co. #1 Mattingly well to the lithologies determined by sample examination. The "clean" "Big Injun" and Berea horizons are easily differentiated from the Sunbury Shale and Cuyahoga shales and siltstones. After examining all the borehole-geophysical-log control within the study area and most of the available sample suites, the author formulated criteria for estimating the amount of "clean" "Big Injun" sandstone based on the gamma ray response. The method employed has certain inherent limitations and, in practice, requires a great deal of subjective data evaluation.

Variations in gamma ray log response caused by slightly dissimilar logging circumstances prevented the use of



Sample depth (ft) (as indicated on sample packet)	
237-241	Shale, medium- to medium-dark-gray. Shale, red
241-330	NO SAMPLES
330-338	Sandstone, quartz, mostly medium-grained, some fine and coarse grained; sorting fair to good; friable (drills as grains); grains subangular to well rounded, clear and frosted. Cement is calcite, dolomite, and quartz?; also some pyritic cement, which oxidizes to rust-colored stain on grains. Trace of white, gray, and amber chert
338-347	Sandstone, as above, with quartz and chert granules, pebbles, and fragments. Also one calcite rhomb 3 x 2 mm
347-353	Sandstone, as from 330-338 ft, no granules, pebbles, or calcite
353-362	NO SAMPLES
362-370	Sandstone, light-gray and light-tan-gray, mostly very fine grained, some fine grained; sorting fair; drills as chips; grains subangular to subrounded, mostly frosted; pyritic and iron stained, fairly tight to slightly porous. Observed contact with silty dolomitic reddish-tan shale (micaceous on partings) indicates that the two lithologies are finely interbedded. Some dark-gray shale (probably cavings)
370-380	As above, except that percent of fine-grained sandstone increases slightly
380-385	Sandstone, quartz, mostly fine-grained, some very fine grained and medium grained; sorting fair; friable (mostly individual grains, 20 percent chips); grains subangular to subrounded, mostly frosted, some clear, others iron stained in part
385-390	As above, except percent of very fine grained sandstone increases
390-397	As above, 50 percent individual grains
397-407	Sandstone, quartz, light-gray and light-tannish-gray, mostly fine-grained and very fine grained; sorting fair; hard (drills as chips); grains subangular to subrounded, mostly frosted. Some color due to iron staining. Cement is dolomite, calcite, and quartz? Minor amount of mica and red and dark minerals, generally concentrated on bedding planes
407-415	As above
415-424	As above
424-434	As above, grain size slightly greater
434-444	Sandy siltstone-sandstone, light-gray, very fine grained, and shale, reddish-tan, silty, dolomitic, commonly micaceous on partings. This sample similiar in appearance to above sample except grain size is smaller
444-451	As above, with slightly greater percent of shale. Also two iron-oxide-colored (silicified?) crinoid disks
451-456	Shale and siltstone, light-gray and reddish-tan
456-458	NO SAMPLES
458-462	Shale, medium-dark-gray. Siltstone, light-gray. Shale, reddish-tan, silty, dolomitic
462-466	Shale, light-gray, with medium-dark-gray and reddish-tan shale. Some unidentifiable carbon imprints on bedding planes of medium-dark-gray shale
466-472	As above
472-478	As above
478-484	As above
484-494	As above, with trace of heavily iron stained fine- to medium-grained sandstone; sorting fair to poor
494-502	As above
502-510	As above
510-516	As above, with increasing amount of medium-dark-gray shale
516-523	Siltstone, light-gray, commonly micaceous on partings. Small amount of silty dolomitic reddish-tan shale containing unidentifiable fragments. Some medium-dark-gray shale (cavings?)
523-533	As above
533-543	Shale, reddish-tan, silty, dolomitic, 30 percent. Siltstone, light-gray, 40 percent. Shale, medium-dark-gray, 30 percent. Trace of poorly sorted fine- to coarse-grained iron-stained sandstone
543-550	As above
550-556	As above
556-561	As above, $1/3$ each type
561-567	As above
567-568	Siltstone, light-gray, 70 percent. Shale, reddish-tan, silty, dolomitic, and dolomite, red, shaly, 15 percent. Shale, medium-dark-gray, 15 percent
568-578	NO SAMPLES
578-584	Same as 567-568 ft
584-805	Samples not described
805-808	Sandstone, quartz, mostly very fine grained, some fine grained; sorting fair; fairly hard (drills as chips); grains subangular to subrounded, frosted; calcite and dolomite cement; some pyrite, many grains iron stained. Shale, medium-dark-gray, 20 percent
808-814	Sandstone, as above, much less iron stain. Shale, medium-dark-gray, 5 percent
814-819	Sandstone, as above, 50 percent. Shale, red, 30 percent. Shale, medium-gray and medium-dark-gray, 20 percent

FIGURE 7.—Borehole geophysical log of the National Associated Petroleum #1 Mattingly well (permit no. 1570) in Licking Township, Muskingum County, and sample description for the interval from the top of the "Big Injun" to the Bedford Shale. Well was drilled by cable tools. Log depths are 2 feet greater than drillers' depths. (Well-casing program: 10¾"—40 feet; 8⅝"—905 feet; 5½"—3304 feet.)

strictly objective lithologic criteria that could be applied uniformly to all control points. Differences in the types of logging instruments and recording equipment among the various service companies, as well as operator-controlled variables such as panel settings, calibration procedures, and logging speeds are the initial impediments. The number of strings of casing (which ranges from none to three) between the sonde and the zone of investigation also significantly affects gamma ray log response. In addition, the fluid level in the borehole, which greatly affects neutron logs, also affects gamma ray logs to a lesser degree.

In order to obviate numerous limitations but still maintain a degree of precision, it was decided to use a comparative approach. Briefly, this method involved establishing for each control point a "clean" sandstone threshold value for the gamma ray log response based chiefly on that of the Berea-Sunbury interval. The gamma ray log response of the overlying sandstone, siltstone, and shale sequence could then be compared to this standard, and deflections to the left of the threshold value (lower counts per second) were tabulated as "net clean sandstone."

Even this basic comparison in many cases was not direct because the "Big Injun" commonly was logged through an additional string of casing. In this event, the gamma ray threshold value was adjusted by applying compensating factors to negate the shielding effect of the additional string of casing. The shielding effect of an additional casing string is illustrated in figure 6; the "Big Injun" was logged through three strings of casing, but the Berea was logged through only two strings.

Figure 7, which illustrates gamma ray and neutron log responses to known lithologies, also serves to illustrate the method of determining the amount of "clean" "Big Injun" sandstone from the gamma ray log. Based primarily on the gamma ray response of the Berea Sandstone, a "clean" sandstone threshold value was established at 4.5 micrograms of radium-equivalent per ton[1]. Unlike many other wells, both the Berea and the "Big Injun" in the #1 Mattingly well were logged through the same number of casing strings (8⅝" surface casing set through the Berea and the 5½" long string) so that no correction factor for the shielding effect of an additional casing string is required. The neutron log of the #1 Mattingly well, however, indicates a fluid level in the borehole at approximately 678 feet. Although the Berea was logged in a fluid-filled borehole and the "Big Injun" was logged in an air-filled one, the effect of the fluid on the gamma ray response appears to be so small that no additional correction factor is applied. The position of the "clean" sandstone line and the resulting number of feet of "clean" "Big Injun" sandstone are shown in figure 7. This determination was made for each well in a similar manner.

FORMATION-WATER SAMPLING

In addition to the reasons enumerated previously under "Purpose and scope," knowledge of the chemical and physical properties of formation waters from producing horizons is necessary for accurate quantitative interpretation of borehole geophysical logs. Water analyses also are used in geochemical prospecting for petroleum and other minerals. Undoubtedly, many analyses of formation-water samples are contained in the files of oil and service companies. However, little information of this nature is published.

Most hydrologic studies of consolidated aquifers in Ohio have been concerned with the identification of potable water supplies. Stout, Ver Steeg, and Lamb (1943), for instance, provided a great deal of generalized nonquantitative information on the surface and subsurface potable water supplies throughout Ohio.

The geographic variation of chemical constituents in formation waters has not been widely investigated in Ohio. Stout, Lamborn, and Schaaf (1932) briefly discussed the main brine-producing horizons in Ohio and listed 81 chemical analyses of brines from formations ranging in age from Silurian to Pennsylvanian. Four analyses of so-called "Big Injun" brines are listed: two from Meigs County and one each from Noble and Monroe Counties. Results of 28 of the brine analyses (including all four of the "Big Injun" analyses) were compiled from other investigators.

Sedam and Stein (1970) mapped the base of potable water (see figure 12 of this report) throughout the state as one aspect of a study of the saline ground-water resources of Ohio. Their elevation contours are based on "chemical analysis of water in deep bedrock wells and on the geology of the producing aquifer systems." They also identify the aquifer in which the base of potable water is thought to occur.

Winslow and White (1966) identified the consolidated, alluvial, and glacial aquifers of Portage County and indicated the quantity and quality of water produced from them. Their report includes a discussion of the stratigraphy of the bedrock formations, which provides valuable insight into the nature of the Mississippian-Pennsylvanian contact in northeastern Ohio.

Comprehensive sampling and field-analysis procedures have been formulated largely as a result of the growing concern with the chemical quality of potable waters. Methods described by Rainwater and Thatcher (1960) were updated and enlarged upon by Brown, Skougstad, and Fishman (1970). Less rigorous sampling and field-analysis procedures applicable to oil-field brine samples are described briefly by Collins (1975).

Commonly, samples of formation water are obtained from the bleeder valves of producing wells after a suitable time subsequent to completion and stimulation procedures. In this manner, representative formation-fluid samples, undiluted by uphole formation waters or drilling, fracturing, and acidizing fluids, can be obtained.

Meents and others (1952) collected and analyzed several hundred brine samples from Illinois oil fields. Most of their samples were obtained from well-head bleeder valves. Some samples, however, were collected from storage, flow, and heater tanks. Meents and others omitted from their report many analyses performed on cable-tool samples obtained from wells in the older producing areas because the samples were "probably more or less diluted with fresher water from strata higher up in the geologic column." A few cable-tool sample analyses were included, but these were largely restricted to wells cased down to the producing formation.

The opportunity to restrict formation-water sampling to stabilized producing wells obviously is limited to formations currently in production. Within the study area at the time of the investigation, no wells were known to be producing from the "Big Injun." Consequently, formation-water samples had to be obtained from wells in the process of being drilled to deeper units.

Oil and gas wells are drilled either by cable-tool, air-rotary, or mud-rotary methods. Wells drilled by mud-rotary

[1]Many of the early gamma ray surveys were scaled in "micrograms of radium-equivalent per ton of formation." Similarly, neutron surveys were scaled in "standard counts per second." The presentation of borehole-geophysical-logging data has been standardized by the American Petroleum Institute. Standard API units now are in general use as scale units for gamma ray and neutron surveys.

rigs can be sampled only by a drill-stem test. Water samples obtained from wells drilled by cable-tool or air-rotary rigs are subject to contamination by uphole aquifers. This type of contamination can be very difficult to detect in sampling air-rotary-drilled wells. In addition, current air-rotary drilling practices almost invariably introduce an additional contaminant of soap solution to formation-water samples obtained from the Berea and younger units. Because of these considerations, cable-tool samples proved to be the best available control. The western part of the study area was sampled exclusively from wells drilled by cable tools (pl. 6). A drill-stem-test sample from a well just east of the study area and several samples from wells drilled by air-rotary rigs in the eastern half of the study area, where cable-tool rigs were not active, also were obtained (pl. 6).

Cable-tool methods

In cable-tool drilling a large-diameter casing (usually 10¾") called a conductor pipe cases off water-bearing unconsolidated sediments, thereby protecting water quality in near-surface aquifers and preventing surface and near-surface waters from infiltrating the borehole. Although excessive amounts are undesirable, some water is necessary in cable-tool drilling. If little or no water is present in the borehole, a barrel or more is added by the driller to enhance the drillability of the formation and, more importantly, to commingle with the chips of rock produced by the drill bit so that a semifluid mixture of water and cuttings is produced. After drilling has proceeded a few feet into the formation, the drilling tools, which are suspended from a steel cable, are pulled out of the hole. The bailer, which is a long cylindrical steel tool having a ball-and-seat-type valve at its base, is lowered to the bottom of the hole by a second steel cable. Contact with the bottom of the well bore unseats the valve and allows the mixture of water and cuttings to fill the bailer. As the bailer is lifted off the bottom of the hole, the weight of the steel ball causes it to seat. The water and cuttings then are lifted to the surface where they are transferred to a surface pit called a "soup-bowl." Generally two to four runs of the bailer are required to remove rock cuttings from the borehole. Additional bailer runs may be necessary to remove excessive amounts of formation water produced by uncased aquifers. The process of bailing down the water level is referred to as "carrying the water." If numerous runs of the bailer have no appreciable effect on the water level in the hole, the condition is referred to as "hole full of water" and the driller reconciles himself to the slower drilling rates caused by the buoyant effect of excess water, which lessens the impact of the drill bit upon the rock.

Under ideal conditions, formation-water samples of excellent quality can be obtained from cable-tool wells. The conductor pipe must effectively seal off near-surface aquifers. Another important requirement is the absence of uncased consolidated aquifers below the conductor pipe. If the well drills dry (water has to be added to the hole in order to drill) to the formation to be sampled, sample integrity is virtually assured. Small flows of "uphole water" (a bailer or two per run) produce dilution effects which are dependent upon the hydrogeologic conditions existing in each well.

In general, where it is more than 50 feet thick, the "Big Injun" produces a "hole full of water" soon after it is penetrated. Although dilution effects on such a large flow of water would appear to be minimal, experience has shown that this is not always the case. Great care, therefore, must be exercised in interpreting chemical analyses of water samples from wells in which dilution is thought to have occurred.

Cable-tool formation-water samples analyzed for this report were obtained from the bailer either by dipping the sample from the top of the bailer or by tripping the bailer into a bucket or pail. Field determinations conducted on water samples consisted of color, odor, taste, temperature, pH, and specific conductance. A 1-liter formation-water sample to which nothing was added was obtained from each well. Where circumstances permitted, a second 1-liter sample, to which 5 milliliters of concentrated nitric acid was added, also was obtained. The acid preservative inhibits precipitation or absorption of certain ions.

Every effort was made to personally collect the open-hole formation-water samples because additional information, sometimes as important as the sample itself, had to be obtained on site in order to evaluate the representativeness of the sample. The driller's log, which commonly is generalized on completion reports, was obtained at the well site. The amount of casing in the hole as well as the depth of the sample was recorded, and the water level in the hole and rate of water production were estimated. Other pertinent information such as the depth, lithology, and water production of "uphole" aquifers, as well as changes in the water level as drilling proceeded, was ascertained by interviewing the driller.

Mud-rotary methods

A drill-stem test to obtain formation-fluid samples from mud-rotary-drilled wells involves removing the hydrostatic head exerted by a column of drilling mud by means of a rubber packer assembly strategically positioned in the drill string. Formation pressure then delivers formation fluids through an opened valve in a testing tool into the interior of the drilling string. After a period of time, the tester valve is closed and pressures are equalized across the packer assembly. Fluids are recovered from the interior of the drill pipe and stems as successive stands of the drill string are uncoupled in removing the apparatus from the hole.

The cost of running a drill-stem test generally limits its use to the evaluation of hydrocarbon-producing zones. A set of water samples from a drill-stem test of the drillers' "Big Injun" ("Maxton" in this case) in a well in Washington Township, Harrison County, east of the study area, was obtained by the author. The tool was opened for a 60-minute flow and over 500 column-feet of fluid was recovered.

Prior to analysis, the drill-stem-test samples were run through a filter press to remove thoroughly dispersed drilling mud. The resulting filtrate was colored by Quebracho extract, a drilling-mud additive. Comparison of the analyses of the drill-stem-test samples with an analysis of a drilling-mud sample from the mud pit shows a great similarity in chemical composition. This similarity suggests that most or all of the fluid recovery from the drill-stem test was mud filtrate from the fresh-water-based drilling mud which had invaded the formation during drilling and logging procedures. Spontaneous potential and gamma ray logs indicate that the interval tested is a thick and porous sandstone probably high in permeability. Estimates of the chloride-ion concentration in the formation water, based on spontaneous potential and resistivity logs, range from 1,500 to 8,500 milligrams per liter (mg/l). The maximum chloride-ion concentration reported in the chemical analyses of the samples recovered from the drill-stem test was 900 mg/l.

Results of this test suggest that it may be difficult to obtain representative formation-water samples from conventional drill-stem tests of the "Big Injun" or similar units because of extensive formation invasion.

Air-rotary methods

Although formation-water samples can be obtained from wells drilled by air-rotary rigs, special procedures are necessary to optimize sample quality. Air-rotary samples are more difficult and time consuming to collect because a greater number of samples per well are required in order to increase the odds of obtaining a representative sample and to evaluate the representativeness of the samples obtained.

Whereas mud-rotary rigs continuously circulate drilling mud to remove rock cuttings from the hole, air-rotary rigs use compressed air as the drilling fluid. The air-rotary method is well adapted to drilling thick sequences of water-free rocks such as the Devonian shale sequence. Mississippian and younger units, however, generally produce small amounts of formation water, which cause rock cuttings to agglomerate on the bit, impeding drilling. On the other hand, large quantities of formation water (commonly encountered in the drillers' "Big Injun") strain the capabilities of the air compressors to blow the water and drill cuttings from the hole. These problems are avoided by using a detergent solution whenever water zones (generally in the Berea and younger formations through which 8⅝" surface casing normally is set) are encountered or expected. The detergent solution is pumped through the drill bit and serves the dual purpose of preventing rock chips from adhering to the bit and acting as a foaming agent to aid the air compressors in removing produced water from the hole. The rock chips and the formation-water/foam mixture are blown up the annular space to an "air head" at the surface which directs the mixture through a flow line ("blooie line") into a surface pit. Water samples obtained from the blooie line are diluted by the detergent solution to a greater or lesser degree depending upon the pumping rate of the soap solution and the amount of formation water produced.

Thirteen usable sets of formation-water samples were collected from wells drilled by air-rotary rigs in the eastern half of the study area. The first set of air-rotary samples was obtained from the Mutual Oil and Gas #1-A Miller well (permit no. 2500) in Clay Township, Tuscarawas County. Discussion of the analytical results of samples from this well illustrates the considerations used to evaluate formation-water sample quality. For this well, samples from the blooie line were taken at 100-foot intervals from the surface to 900 feet (through the Berea). In addition, a sample was taken at 425 feet, where the flow from the return line was slightly greater than normal. Chemical analyses of the samples reveal that concentrations of chloride ion increase slightly from the 100-foot sample to the 300-foot sample (table 1) and rapidly increase in the samples from 400 feet to 500 feet owing to the addition of "Maxton" formation water. TDS concentrations are variable above 500 feet. The top of the "Maxton" is estimated at a depth of 372 feet on the basis of the observed drilling rate. Chloride-ion and TDS concentrations are fairly constant from the 500-foot samples through the 900-foot samples.

The Berea Sandstone was encountered at approximately 872 feet so its formation water should be commingled in the 900-foot sample. Because there is little change in the chloride-ion or TDS content of the 900-foot sample, it appears that (1) the Berea is contributing little or no formation water to the sample, or (2) the dilution factor is high, or (3) both conditions are true.

TABLE 1.—*Chloride-ion and total dissolved solids (TDS) concentrations in the #1-A Miller well sample suite (formation-water sample no. 20, Tuscarawas County well-permit no. 2500).*

Sample depth (ft)	TDS concentration (mg/l)	Chloride-ion concentration (mg/l)
100	322	10.5
200	1,008	
300	582	52.5
400	1,076	420
425	1,570	714
500	2,534	850
600	2,576	892
700	2,504	902
800	2,498	992
900	2,500	1,039

Water flow from the blooie line increased only slightly after encountering the "Maxton" (drillers' "Big Injun"). Therefore, much of the volume of the 400- to 900-foot water samples is thought to be a mixture of uphole formation water and soap solution. Because of an apparently large dilution factor, none of the samples are judged to be highly representative of the "Maxton" formation water, and sample quality is rated as extremely poor to fair (table 2). Even so, such analyses are considered valuable because they establish minimum concentration levels at a given location. As additional sample analyses from surrounding wells are obtained, a fairly accurate interpretation of the geographic variation in formation-water quality can be formulated.

CHEMICAL ANALYSIS

Formation-water samples were chemically analyzed substantially in accordance with the methods described by Brown, Skougstad, and Fishman (1970). Elemental concentrations of sodium, potassium, calcium, magnesium, silicon, iron, and manganese were determined by atomic absorption using a Perkin-Elmer Model 303 atomic absorption spectrophotometer. Alkalinity or acidity was determined by titrimetric methods. Bicarbonate and carbonate analyses were calculated from the results of the alkalinity titration. Hardness was calculated from the results of the calcium, magnesium, and bicarbonate determinations. Sulfate was determined by the turbidimetric method in accordance with American Public Health Association (APHA) standard methods (1971). Chloride-ion concentration was determined by titration using a modification of the Mohr method. Total dissolved solids were determined by drying at 180°C and weighing.

Although a large volume of data was generated by analyses of multiple samples from most wells, for several reasons it was decided to present only the chloride-ion and TDS determinations for the single sample judged to be most representative of the "Injun" or "Maxton" at each sampling location. First, detailed water-quality analyses require considerable space to present and are not thought likely to be of general interest. Secondly, the accuracy of certain of the determinations is somewhat suspect owing to sampling and/or analytical concerns. Thirdly, the results, although reported in quantitative terms, have only qualitative significance because of unknown degrees of dilution. The latter circumstance greatly overshadows any other possible source of error. Lastly, TDS and chloride-ion concentrations were

TABLE 2.—*Chloride-ion and total dissolved solids (TDS) concentrations in "Big Injun" and "Maxton" formation-water samples*

Formation-water sample no.	County	Township	Land subdivision	Permit number	Control type[1]	"Big Injun" interval (ft)	"Maxton" interval (ft)	Sample depth (ft)	Chloride-ion concentration (mg/l)	TDS concentration (mg/l)	Sample quality	Remarks
1	Muskingum	Falls	2 Qtr, T 1,R 8	3408	D	430-480		200-300	4,376	7,870	poor to good	well depth at time of sampling: 480 ft; sample depth: depth of bailer in casing
2	Muskingum	Newton	Sec. 1 (NW)	3446	D	400-650		690	640	1,712	extremely poor to poor	sample from bottom of hole after well sat idle overnight
4	Muskingum	Adams	Sec. 25	3453	D	605-655		700	35,908	60,300	fair to good	
6	Harrison	Washington	Sec. 14	268	L		726-874	726-900	900	3,220	very poor to fair	drill-stem-test sample from top of testing tool
10	Muskingum	Washington	3 Qtr	3508	D	480-520		420	5,194	9,000	very poor to fair	sample obtained from bailer run inside of surface casing set at 530 ft
11	Coshocton	Bedford	Sec. 25	2465	L	384-555		400	67	632	poor to good	commingled "Big Injun" and overlying aquifers
12	Muskingum	Adams	Sec. 25	3540	D	590-655		600	3,368	6,150	very poor to poor	thought to be greatly diluted by uphole water
13	Muskingum	Perry	Sec. 9	3543	D	570-595		620	6,160	11,390	extremely poor to poor	thought to be greatly diluted by uphole water
14	Muskingum	Adams	Sec. 25	3580	D	598-650		200?	7,838	13,690	very poor to poor	sample collected by driller on fifth run of bailer inside surface casing just after landing
15	Coshocton	New Castle	3 Qtr	2625	D	190?-450+		400	22	322	extremely poor to fair	probable dilution by uphole sandstones, which may or may not be in hydrologic continuity with "Big Injun"
17	Coshocton	Pike	Sec. 2	2639	L	370-534		410	13	322	poor to good	probable dilution by uphole sandstones, which may or may not be in hydrologic continuity with "Big Injun"
18	Muskingum	Clay	Sec. 15	3608	D	485-605		489	7,987	13,614	fair to very poor	commingled "Big Injun" and overlying aquifers; sampled by driller
19	Muskingum	Brush Creek	Sec. 28	3627	D	725-750		725	5,593	10,340	very poor to fair	commingled "Big Injun" and overlying aquifers
20	Tuscarawas	Clay	Lot 10, Gnaden-hutten Tr.	2500	D		372-425+	600	892	2,576	extremely poor to fair	formation water diluted by foaming-agent solution
21	Muskingum	Washington	Sec. 9	3618	D	466-488		200	5,824	10,200	excellent to good	sample obtained just prior to mudding of surface casing set at 498 ft
22	Muskingum	Harrison	Sec. 17	3628	D	815-868		832	44,321	75,150	excellent to good	
107	Guernsey	Center	Sec. 2 (N)	1921	G		689-715	718	19,394	34,160	poor to fair	
108	Tuscarawas	Washington	Lot 29, 1 Qtr	2628	L		514-638	400	5,211	9,350	extremely poor to fair	reported water quality that of an uphole aquifer, but also considered a minimum value for "Maxton," although "Maxton" sample had fewer TDS
109	Tuscarawas	Perry	Sec. 5	2640	L		677-897	934	4,966	9,088	good to fair	
110	Guernsey	Wheeling	Sec. 9 (E)	1947	D		670-834	700	18,887	34,950	very good to fair	samples obtained by drilling crew
111	Tuscarawas	Perry	Sec. 4	2644	L		619-840	830	8,642	16,410	very good to fair	
112	Guernsey	Center	Sec. 8	1951	G		700-740	893	60,467	122,700	very good to fair	very little sandstone or formation water encountered; samples obtained by drilling crew
113	Tuscarawas	Perry	Sec. 4	2642	L		629-866	1,059	9,028	16,550	very good to fair	
114	Guernsey	Center	Sec. 7	1954	D		714-974	922	34,599	73,100	good to fair	samples obtained by drilling crew
115	Tuscarawas	Oxford	Sec. 21	2629	D		402-696	400	1,326	2,598	poor to very poor	samples obtained by drilling crew; TDS concentration less in sample from 510 ft
116	Tuscarawas	Perry	Sec. 7	2651	L		772-975	1,191	11,086	21,290	excellent to good	
117	Guernsey	Center	Sec. 12	1957	D		812-1,016	946	33,148	58,820	good to fair	samples collected and labeled by drilling crew
118	Tuscarawas	Perry	Sec. 4	2643	L		724-958	1,023	9,489	16,870	very good to fair	

[1]L, borehole geophysical log; D, drillers' log; G, sandstone interval picked by author from geolograph at well site.

used almost exclusively for water-quality interpretation. These results are presented in table 2. Isocon lines for 3,000 and 35,000 mg/l TDS are shown on plate 6. For the interested reader, complete analytical results are on file with the Division of Geological Survey.

RESULTS OF INVESTIGATIONS

STRATIGRAPHY

A net "clean" sandstone isopach map (pl. 2) of the drillers' "Big Injun" illustrates two sandstone "fairways," each with a general north-south trend, separated by a large central area consisting predominantly of shale and siltstone. Ver Steeg (1947) considered the eastern sandstone body to be part of an extensive sandstone and conglomerate facies-equivalent of the western sandstone body ("Big Injun"), separated from it by an unnamed shale facies. This correlation was made on the basis of structural and stratigraphic position and lithologic similarity. An isochore map (pl. 3) of the interval from the top of the Berea Sandstone to the base of the eastern or western sandstone unit illustrates the similarity in stratigraphic position of the two sandstone bodies. Within the study area, the approximate range in thickness of the rocks separating the sandstone bodies from the Berea Sandstone is 300-460 feet. Thickness changes are most erratic in the northeastern part of the study area. These rapid thickness variations are believed to be associated only with the eastern sandstone body and are not considered to be merely the result of increased well-control density.

Even though variations in sandstone thickness and changes in lithology from sandstone to shale are very rapid in the western sandstone body, transitions are observable in the gamma ray log signature and are interpreted as evidence that the lithologies are in facies relationship. By way of contrast, the erratic changes in lithology and thickness observed in the eastern sandstone body are unaccompanied by identifiable transitions in log character, suggesting that the sandstone bears little genetic relationship to the shales and siltstones enveloping it. The aforementioned subtle differences in log character prompted additional geologic investigation north of the study area. The results of this additional research, which will be discussed later, confirmed the previously intuitive practical necessity of considering the eastern and western sandstone bodies separately.

Western sandstone body

Age.—The western sandstone body is Mississippian in age and can be traced, using closely spaced borehole-geophysical-log control, westward to the type locality of the Black Hand Sandstone Member. Outcrops of the Black Hand contain Mississippian fossils, and the subsurface equivalent, the "Big Injun" sandstone, in western Coshocton and western Muskingum Counties is overlain by younger Mississippian clastics. In southern Muskingum County these younger clastics are capped by erosional remnants of the Maxville Limestone. Figure 8 illustrates the distribution of the Maxville Limestone in southeastern Ohio.

Environment of deposition.—Previous investigators intensively studied outcrops of the Black Hand Member in an effort to determine its environment of deposition and sediment source. Hicks (1878, p. 217) theorized that the Black Hand Member in the vicinity of Hanover represents an ancient shore deposit exhibiting "... the typical structure of a seabeach." Hyde (1915, p. 669) suggested "... that the visible portion of the conglomerates at least were built forward by currents of considerable strength, either as a sand-spit," or as a delta. Holden (1942, p. 65-66) considered the conglomerate to be the result of deltaic deposition in marine waters by streams of considerable volume, steep gradients, and short courses. Ver Steeg's (1947) opinion on this matter, which incorporates the conclusions of previous workers, has been reported earlier (p. 6). More recently, Bork and Malcuit (1979) concluded that the Black Hand Sandstone Member in its area of outcrop in central Ohio represents distributary-mouth and barrier-bar deposits.

The gamma ray log character and the geometric configuration of the thick sandstone sequence illustrated in the western part of the net sandstone isopach map (pl. 2) suggest a deltaic mode of deposition. The rapid changes in sandstone thickness and rapid transitions from sandstone to shale (illustrated in cross sections A-A′ and B-B′, pl. 1) are consistent with this interpretation. Affected most by these changes are the middle and lower parts of the sandstone interval, which appear to represent a fluvial, distributary-channel, or distributary-mouth-bar phase of Black Hand deposition. The uppermost part of the western sandstone unit is least affected by these changes and is persistent to west-central Coshocton and central Muskingum Counties. The latter appears to represent a sheet phase of Black Hand sedimentation.

Sediment source.—Herrick (1887, p. 9-10) suggested that the source of the Black Hand material was to the northeast. However, directional structures along the outcrop, first mentioned by Hicks (1878, p. 217), although somewhat variable, generally indicate a northerly component of sediment transport. Available field evidence summarized by Holden (1942) suggests a southeastern source area. Subsurface evidence of a northwest-trending distributary channel connecting the western sandstone body with its postulated source area would substantiate theories of a southeastern sediment source. No such channels are indicated on the net sandstone isopach map (pl. 2) or on Ver Steeg's facies or thickness maps (figs. 5 and 6). Although Ver Steeg (1947, p. 726-727) conceded that the paleocurrent direction appears to be from the south and southeast, he still maintained that the ultimate source of the quartz conglomerate was to the northeast and north.

Because of the limited scope of this investigation, no attempt has been made to reinterpret outcrop data on the Black Hand Member. Furthermore, the available data are sufficiently inconclusive to prevent previous investigators from agreeing on the mode of deposition or the source area for the Black Hand. A conclusive solution to the problem of the source area for the western sandstone body awaits a detailed petrographic study that would integrate grain size and roundness determinations with a study of trace mineral distribution. Such an investigation should be regional in scope and include petrographic analyses of outcrop samples of the Black Hand and well cuttings of the "Big Injun." However, at the present time there is inadequate sample control for such a study.

Pepper, de Witt, and Demarest (1954, p. 94) postulated a northerly and northeasterly source for most of the Berea Sandstone in Ohio on the basis of detailed petrographic studies of well samples by Rittenhouse (1946) and other evidence. An easterly source for the Berea in southeastern Ohio and West Virginia also was identified. Fuller (1955, p. 171-174) identified a northern source for the Sharon

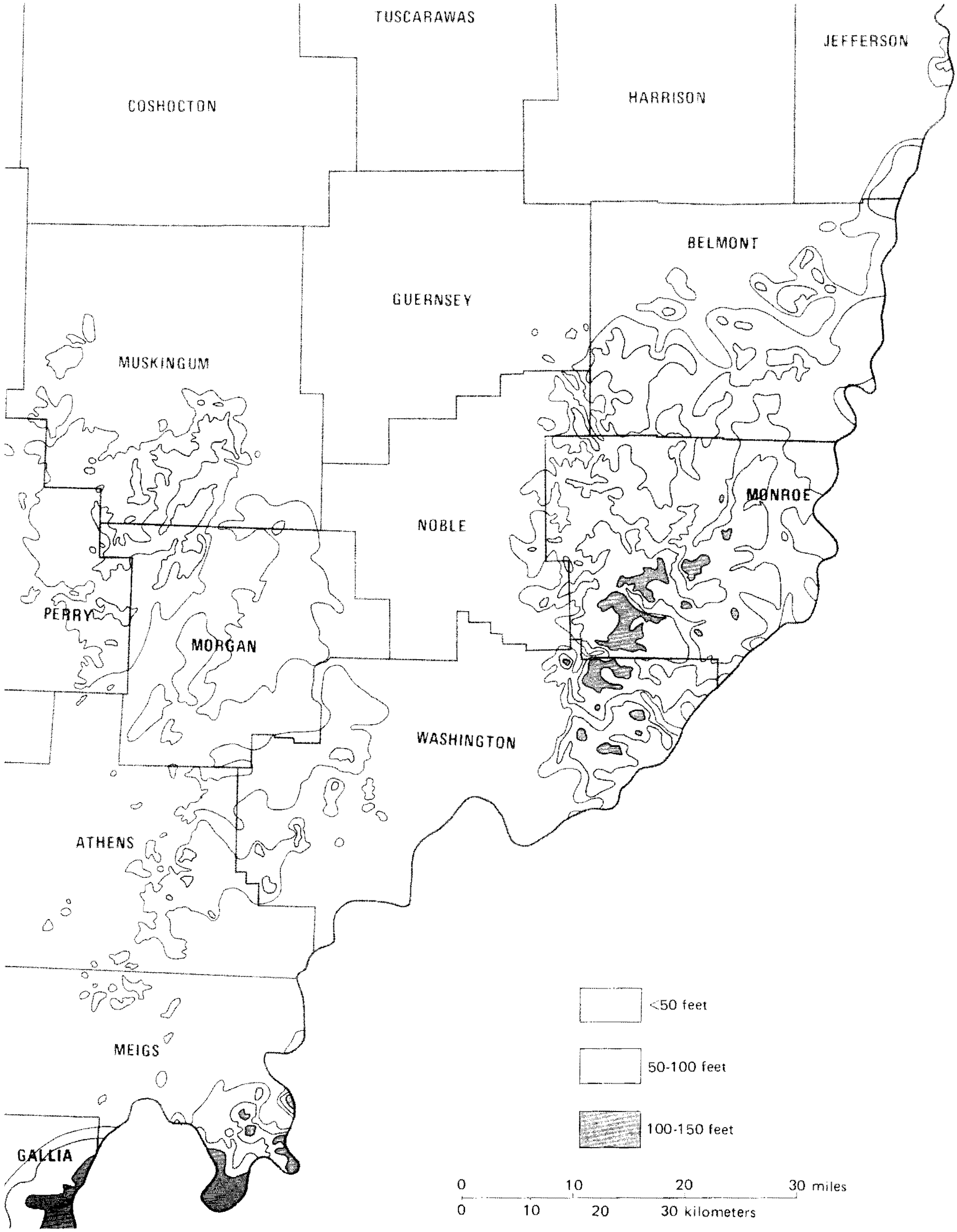


FIGURE 8.—Generalized isopach map of the Maxville Limestone in southeastern Ohio (modified from Uttley, 1974, pl. 2).

exposures in northeastern Ohio and suggested a southeastern source for the Sharon outcrops in southeastern Ohio. The Black Hand Member is thus bracketed by clastic sequences derived predominantly from a northern source area. Uttley (1974) cited regional studies by Potter and Pryor (1961), Swann (1963), Arkle (1972), and Pepper, de Witt, and Demarest (1954) as well as investigations in northeastern Ohio by Lamb (1911), Bowen (1952), and Fuller (1955) and a study in western Pennsylvania by Adams (1964) in concluding "that a long-term southerly paleoslope existed in Ohio and adjacent areas through Carboniferous, if not most of later Paleozoic time."

Not all investigators would concur with the conclusions cited above, and inferred source directions for overlying and underlying clastics do not prove a source direction for a unit sandwiched in between. However, lacking compelling evidence to the contrary, such circumstances shift the burden of proof to those who would invoke a source direction opposite the one which appears to predominate.

Ostensibly, the predominantly northerly directional structures observed along Black Hand outcrops by previous investigators appear to be compelling. However, their statistical validity might be questioned, particularly in view of recent substantial improvements in methods of interpreting paleoenvironments. The number and location of the measurements, the degree to which observed paleocurrent indicators have been matched to specific environments or subenvironments of deposition, and their position within the vertical sequences have not been reported, except in general terms.

The only inference that can be drawn from the present investigation is that, within the study area, the geometry of the western sandstone body suggests deltaic deposition; its orientation, therefore, suggests either a northerly or a southerly source area. Field evidence appears to require a northerly sediment-transport direction, and available information suggests that a connection to an upstream segment of the fluvial-deltaic system should be looked for in the Meigs, Athens, and Gallia Counties area. Because of other considerations cited above, the author, like Ver Steeg (1947), continues to entertain the hypothesis that the ultimate source of the coarse clastics was to the north or northeast, partly in the hope of instigating a regional subsurface investigation of the "Big Injun."

Eastern sandstone body

Age.—Uncertainty regarding the correlation of the eastern and western sandstone bodies, reinforced by subtle differences in sedimentation patterns as interpreted from gamma ray logs, sparked an interest in the nature of the purported "Big Injun" sandstone north of the eastern half of the study area. Of particular interest was the 100-foot-thick "Big Injun" sandstone in southwestern Portage County shown on Ver Steeg's isopach map (fig. 5). Examination of borehole geophysical logs from Suffield Township, Portage County, revealed that the interval separating the base of the so-called "Big Injun" from the Berea Sandstone was much thinner than normal and differed greatly within short distances, in marked contrast to the fairly consistent interval (commonly 360 to 420 feet) separating these horizons within the study area. In the Atlas Minerals Corp. #1 Saylor well in lot 5, Suffield Township, the "Big Injun" and the Berea are separated by less than 110 feet.

Although explanations such as depositional thinning or an intraformational disconformity were considered, the author believes that the proximity of the two sandstone units is best explained as resulting from the systemic unconformity. The "Big Injun" in this area, then, is not the subsurface equivalent of the Black Hand Sandstone (Mississippian), but rather is the subsurface equivalent of the Sharon sandstone and conglomerate (Pennsylvanian) (the drillers' "Maxton"). This interpretation agrees with hydrogeologic investigations in the area by Sedam (1973), Sedam and Stein (1970), and Winslow and White (1966), who identified the aquifer at this stratigraphic position as the Sharon. In addition, Arie Janssens (personal commun., 1976) observed the improper usage of the drillers' term "Big Injun" in Portage County, where the name has been applied to subsurface sandstone bodies that can be traced to Sharon outcrops.

As outlined above, the evidence fairly conclusively establishes the Pennsylvanian age of the so-called "Big Injun" in Portage County. Furthermore, correlation of the thick sandstone unit above the Berea Sandstone southward, as illustrated in cross section F-F′ (pl. 1), strongly suggests that the entire eastern sandstone "fairway," referred to as "Big Injun" by previous investigators, also is Pennsylvanian in age.

An alternative explanation is that the "Maxton" in northeastern Ohio is contiguous with an eastern subsurface equivalent of the Black Hand as a result of a cut-and-fill relationship associated with the systemic unconformity. An interface of this nature could occur anywhere south of the northernmost Stark County well in cross section F-F′. Identification of an unconformity of this nature in the subsurface without adequate sample control, however, would be difficult if not impossible owing to the similarity of the two units.

The author favors correlating the entire eastern sandstone body with the Sharon because this interpretation is consistent with both geologic observations and the results of the formation-water investigation.

Environment of deposition.—The eastern sandstone body appears to be a continuation of the fluvial-deltaic system of Pennsylvanian age identified by Lamb (1911), Bowen (1952), Fuller (1955), and other investigators. Mrakovich's (1969) interpretation of sedimentary structures in outcrops of the Sharon in Summit County favors the fluvial end member of the fluvial-deltaic continuum in that area.

Available subsurface information also supports a fluvial-deltaic origin. Erratic sandstone development and rapid changes in thickness from the base of the eastern sandstone body to the Berea suggest paleogeomorphological control of sedimentation enhanced by channeling. Cross section G-G′ (fig. 9) illustrates an interpreted cut-and-fill relationship in southern Tuscarawas County.

The sharp basal contact commonly observed on gamma ray logs and the dendritic pattern of the interpreted channels suggest fluvial deposition on a dissected erosional surface. Deposition of the eastern sandstone body probably took place in a wide valley scoured in the Mississippian surface.

Sediment source.—The Cuyahoga Formation and younger rocks probably were subjected to post-Mississippian erosion in much of northeastern Ohio (Szmuc, 1957). Thus coarser clastics such as the Black Hand may have been recycled, so that at least a small part of the source for the Sharon may have been local.

Fuller (1955) presented convincing evidence of a northern source for the Sharon conglomerate exposed in Cuyahoga, Geauga, Lake, Medina, Portage, Summit, Trumbull, and Wayne Counties. He interpreted secondary growth on most of the quartz grains as evidence that the Sharon sediments

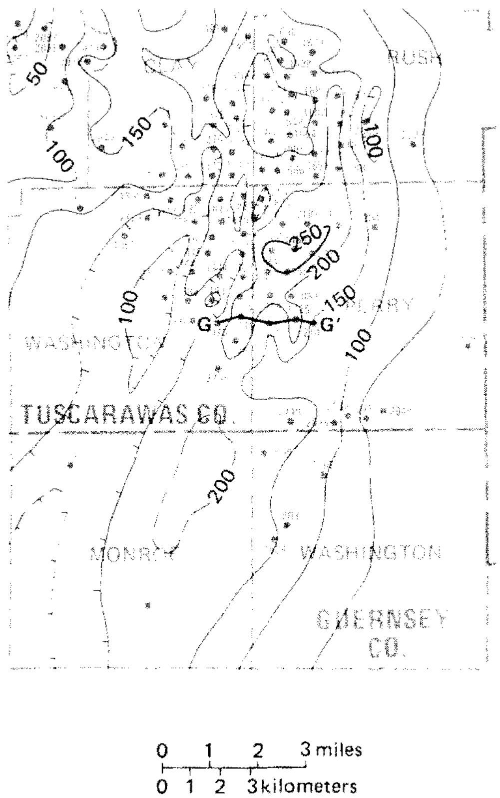
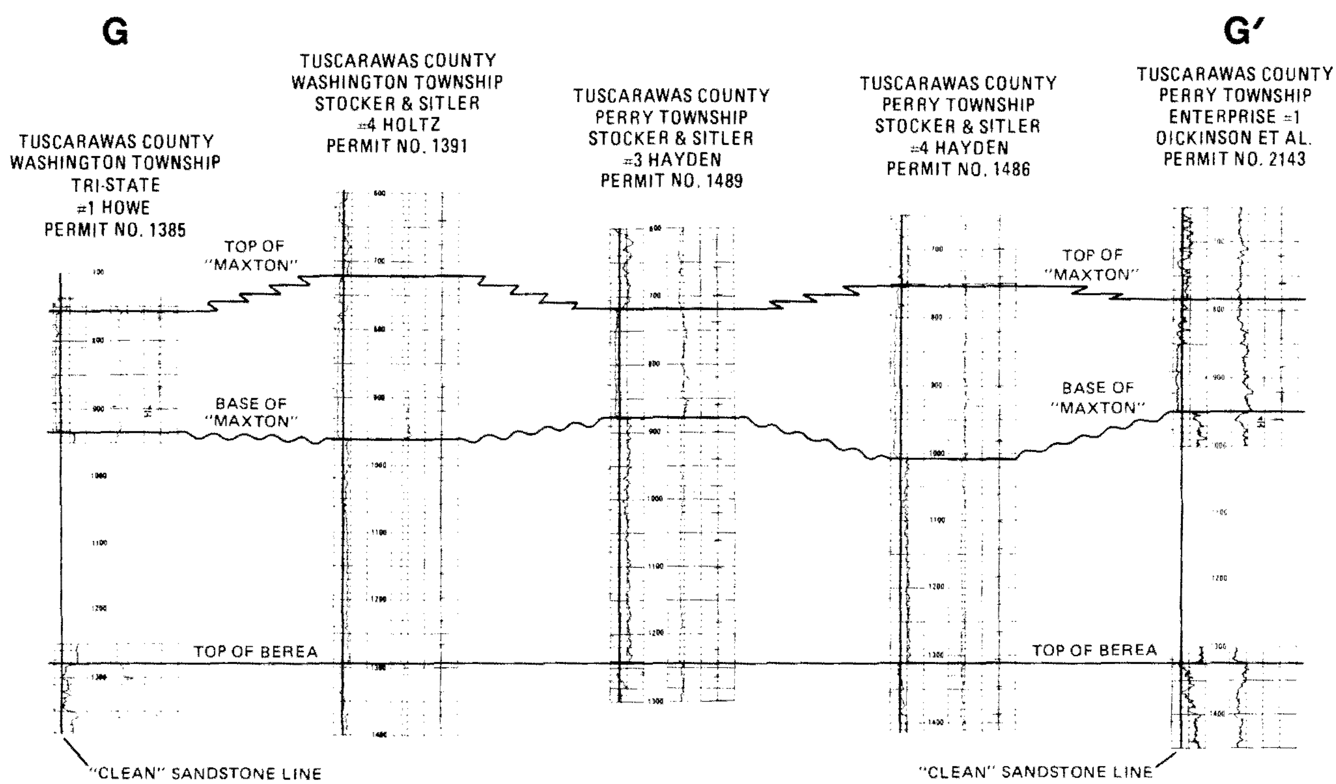


FIGURE 9.—Isopach map and geophysical-log cross section illustrating channeling in the "Maxton" sandstone in Guernsey County (isopach map is a portion of pl. 2).



have been subjected to more than one cycle of sedimentation and may be several cycles removed from the original source rocks. Fuller (1955) considered the immediate source area to be a highland in Canada composed of a pre-Pennsylvanian sequence of well-cemented quartzite, sandstone, conglomerate, and limestone. Fossil evidence cited by Fuller (1955) proves that at least part of the source was Middle Devonian (Onondagan-Hamiltonian) in age.

Geologic history.—The Logan and Cuyahoga Formations and possibly the Maxville Limestone probably originally extended over the entire study area and throughout most of eastern Ohio. These units were removed to a greater or lesser extent by erosion in much of eastern Ohio and throughout most of the eastern half of the study area. Low north-south ridges may have developed on the exposed Mississippian rocks and may have served to control development of drainage systems, resulting in the formation of strike valleys. Fluvial processes apparently scoured wide north-south valleys in which the Sharon sandstone/conglomerate was deposited and preserved. Deposition of lowermost Pennsylvanian sediments was restricted to topographic lows in the dissected Mississippian surface. Younger Pennsylvanian rock units progressively overlapped the Sharon and abutted successively younger rocks of Mississippian age. Figure 10 illustrates suggested relationships of the mapping units and adjacent strata.

STRUCTURE

The generalized structure contour map of the top of the Berea Sandstone (pl. 4) was prepared using the same wells used to delineate the "Big Injun" and "Maxton." Many additional gamma ray logs of the Berea section are available, but no attempt was made to include this control. Plate 4 illustrates a southeasterly regional dip, interrupted in the central region of the study area by the northwest-southeast-trending structural feature known as the Cambridge Arch. With minor variations, the features observed on the Berea structure map also are observable on the map of the elevation of the base of the "Big Injun" and the base of the "Maxton" (pl. 5).

According to Clifford and Collins (1974), the Cambridge Arch follows the pinchout of the Salina E salt (Silurian) and is the result of thin-skinned thrusting on a Salina glide plane. Recent detailed structure mapping by Gray (1982) has shown that the Cambridge Arch, and the associated Parkersburg-Lorain Syncline, are detached folds present only above the base of the Cleveland Shale Member of the Ohio Shale (Upper Devonian). Northwestward thrusting was initiated along Silurian salt beds in the central Appalachians and extended to the western pinchout of the salt in western West Virginia, where the slip surface cut upward toward the surface (Rodgers, 1963). In Ohio, the décollement surface ramped upward through the Middle Devonian limestones into the Upper Devonian shale sequence. Thrusting and folding of units above the shale formed the Cambridge Arch; the Parkersburg-Lorain Syncline is a passive feature. The western edge of the thrust sheet coincides with the western edge of Salina evaporite deposition, and Gray (1982) has postulated that both are controlled by northwest-trending basement faults.

Gray's (1982) mapping and the similarity in structure on plates 4 and 5 indicate that the present structural configuration is the result of post-Pennsylvanian thrusting, which probably occurred during the Alleghenian Orogeny.

FORMATION-WATER QUALITY

The eastern sandstone body has been considered to be a down-dip facies-equivalent of the western sandstone body

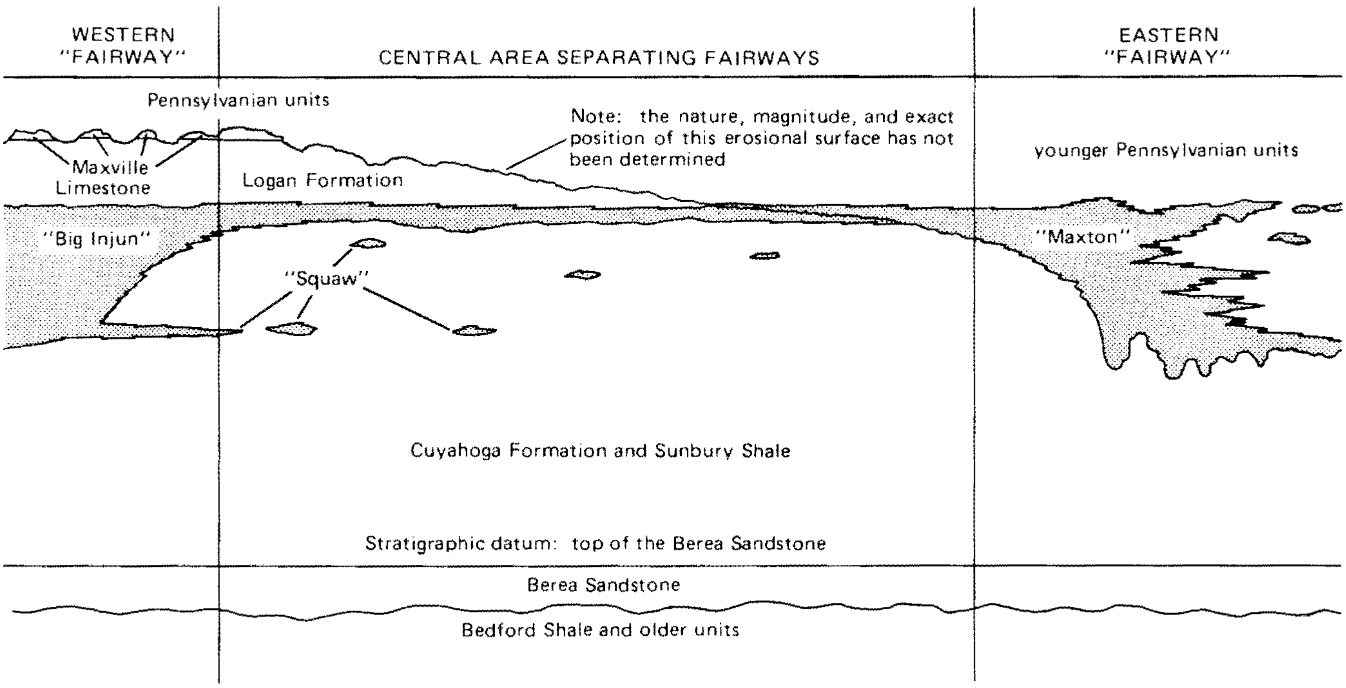


FIGURE 10.—Diagrammatic east-west stratigraphic cross section illustrating suggested subsurface relationships of the mapping units and adjacent strata in the study area.

because of its similar stratigraphic and structural position. The rocks have a homoclinal southeasterly dip into the basin and the sandstone is encountered at greater depths to the east, so it was generally assumed that formation water in the eastern sandstone body ought to be more saline than that in the western sandstone body because of greater depth to the aquifer and increased distance from the presumed recharge area (Black Hand outcrops). On the basis of these assumptions, it seemed highly anomalous to encounter drillers' records in Tuscarawas and Guernsey Counties which record "fresh water" in a rock unit identified as the "Big Injun." Subsurface investigation revealed that many of the sandstone horizons labeled as "Big Injun" actually were aquifers geologically younger than the eastern sandstone body, thereby compounding the miscorrelation. Other sandstone horizons, particularly in Tuscarawas County, could be correlated to the eastern sandstone body. The apparent formation-water anomaly is readily explained, however, if the eastern and western sandstone bodies are independent hydrologic units, as shown by this study.

Usable formation-water samples were obtained from 14 wells penetrating the western sandstone body, 13 wells penetrating the eastern sandstone body, and one well just east of the study area in Harrison County (pl. 6). The representativeness of each sample was evaluated by critically examining its chemical analysis, estimating the effects of uphole water zones where present, and comparing the results to analyses of samples from surrounding wells. Subjective sample-quality ratings, which ranged from excellent to extremely poor, were assigned to each sample based on the above criteria. Table 2 lists sampling information, chloride-ion and TDS concentrations, and sample-quality evaluations for each well sampled. Because of the difficulty of obtaining uncontaminated formation-water samples from uncased wells, only a small percentage of samples is considered highly representative.

The foregoing discussion explains why the isocons on plate 6 are not simply mechanical contours of the concentrations reported at each of the water-sample control points. The 3,000 and 35,000 mg/l TDS isocons on plate 6 delineate the fields of potable water (<3,000 mg/l), potentially treatable brackish water (3,000-35,000 mg/l), and brine (>35,000 mg/l).

Western sandstone body

TDS and chloride-ion concentrations in the formation water of the western sandstone body increase away from the outcrop area in a southeasterly and easterly direction, as might be expected. Potable water is thought to be present in the "Big Injun" west of the 3,000 mg/l isocon shown on plate 6. Brackish water is thought to be present in the remainder of the western sandstone body where the net "clean" sandstone thickness is greater than 50 feet.

The 3,000 mg/l TDS isocon swings northeastward in the northern part of the study area, probably owing to the relatively shallow depth to the "Big Injun." The "Big Injun" in this area may receive recharge from surface waters in alluvial aquifers which communicate with the "Big Injun" sandstone through interconnected Mississippian (and Pennsylvanian?) aquifers.

West-central part of study area

The persistent less-than-50-foot-thick sandstone unit in the western two-thirds of Muskingum and Coshocton Counties is part of the "Big Injun" or western-sandstone aquifer system. West and north of the 35,000 mg/l TDS isocon, brackish water most likely will be encountered in the "Big Injun" sandstone. East and south of the 35,000 mg/l TDS isocon, brine can be expected. The eastern limit of the sandstone affiliated with the western-sandstone aquifer system is difficult to determine. Available information suggests that this boundary lies roughly north-south through the eastern boundaries of Blue Rock and Salt Creek Townships, Muskingum County (pl. 2). The stratigraphic relationship of the remainder of the thin sandstone units in the area separating the eastern and western sandstone bodies and the quality of the formation water contained therein is not known accurately.

Eastern sandstone body

TDS and chloride-ion concentrations in the formation water of the eastern sandstone body increase in a southerly to southeasterly direction. Sedam and Stein (1970) concluded that potable water is present in the Sharon sandstone in northernmost Tuscarawas County (see figure 12 of this report). Their interpretation is consistent with the findings of this formation-water investigation, which predicts that brackish water will be encountered in the southern half of Tuscarawas County. Brine is expected within the eastern sandstone body throughout most if not all of Guernsey County.

Summary of formation-water investigations

Although available subsurface information does not preclude the possibility of limited hydrologic interaction in the area separating the sandstone units, the results of the formation-water investigation indicate that the eastern and western sandstone bodies behave as independent hydrologic systems. TDS and chloride-ion concentrations increase with increasing distance from the respective recharge areas and as depth to the rock unit increases.

FEASIBILITY OF OIL-FIELD-BRINE DISPOSAL IN THE "BIG INJUN" AND "MAXTON" SANDSTONES

The results of the formation-water investigation indicate that potable water is present in the "Big Injun" sandstone in westernmost Coshocton and Muskingum Counties. In the remainder of the study area, brackish water and brine occupy the pore volume of the eastern and western sandstone bodies, except locally where minor accumulations of oil and gas are present. A general understanding of the in-situ formation fluids is necessary to assess the feasibility of using the sandstone bodies for oil-field-brine disposal.

IN-SITU FORMATION FLUIDS

Oil and gas

According to the most recent *Oil and gas fields of Ohio* map (Ohio Geological Survey, 1974), 52 pools or fields in the state produce from the "Injun" sandstone, all in counties east and south of the study area. As previously noted, the drillers' term "Injun" or "Big Injun" has been applied with varying degrees of accuracy. In light of the findings of the present investigation and the correlation difficulties noted by previous investigators, it appears highly unlikely that all or even most of these fields produce from sandstone units which are stratigraphically equivalent to the Black Hand Sandstone Member. Regardless of the correlation, the small size, sporadic distribution, and limited number of producing areas have minimized the importance of the "Big Injun" as a primary exploration target.

In his investigation of the petroleum geology of Muskingum County, Cummins (1931) included a discussion of the Black Hand sandstone ("Injun sand"): "In Union Township this formation has been found to contain commercial quantities of gas, but the structure is not easily determined, and unless the well is drilled on the crest of an anticlinal structure the salt water quickly spoils the well" (p. 26-27). Figure 11 reproduces Cummins' illustration of the structure associated with the "Big Injun" production in Union and Rich Hill Townships. Referring to this illustration, Cummins (1931, p. 27) explained:

> The contours, drawn from the well records only, indicate that gas has accumulated at the crest of an irregular anticline with a general north-south axis. Altho wells not on the crest of the structure have produced gas, the amount of gas was small and the wells were soon spoiled by encroaching salt water .... Small shows of gas have been reported from the "Injun" sand in several other localities, but no attempt has been made to obtain production from this horizon except in Union Township.

Small flows of gas have been obtained from the drillers' "Big Injun" in various parts of the study area (Lamborn, 1956, p. 265; Stout, 1918, p. 322). Shows of gas also have been encountered in the eastern sandstone body ("Maxton") during the drilling of "Clinton" wells in Spencer Township, Guernsey County (James P. Sigler, personal commun., 1975). The pressure of this gas, however, is low compared to gas-pipeline pressure, so that compressors are required to establish commercial production from this shallow horizon. To date, economic incentive has been insufficient to justify capital expenditures for shallow well completions and installation of a centrally located compressor unit. As a result, the commercial feasibility of producing gas from the "Maxton" in this area remains unevaluated. Past experience and available information suggest that within the study area, production from either the eastern or western sandstone body generally will be subcommercial. However, local accumulations of natural gas might be encountered that would be suitable for light industrial applications or agricultural and domestic uses.

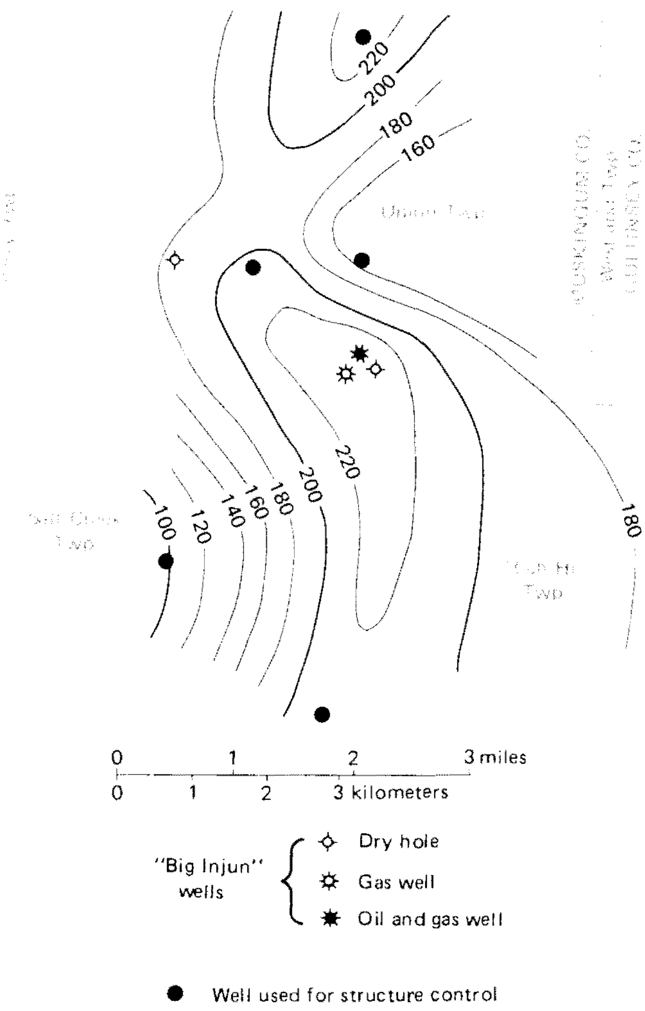


FIGURE 11.—Structure on the "Injun" sandstone in Union and Rich Hill Townships, Muskingum County (modified from Cummins, 1931, fig. 5).

Brine

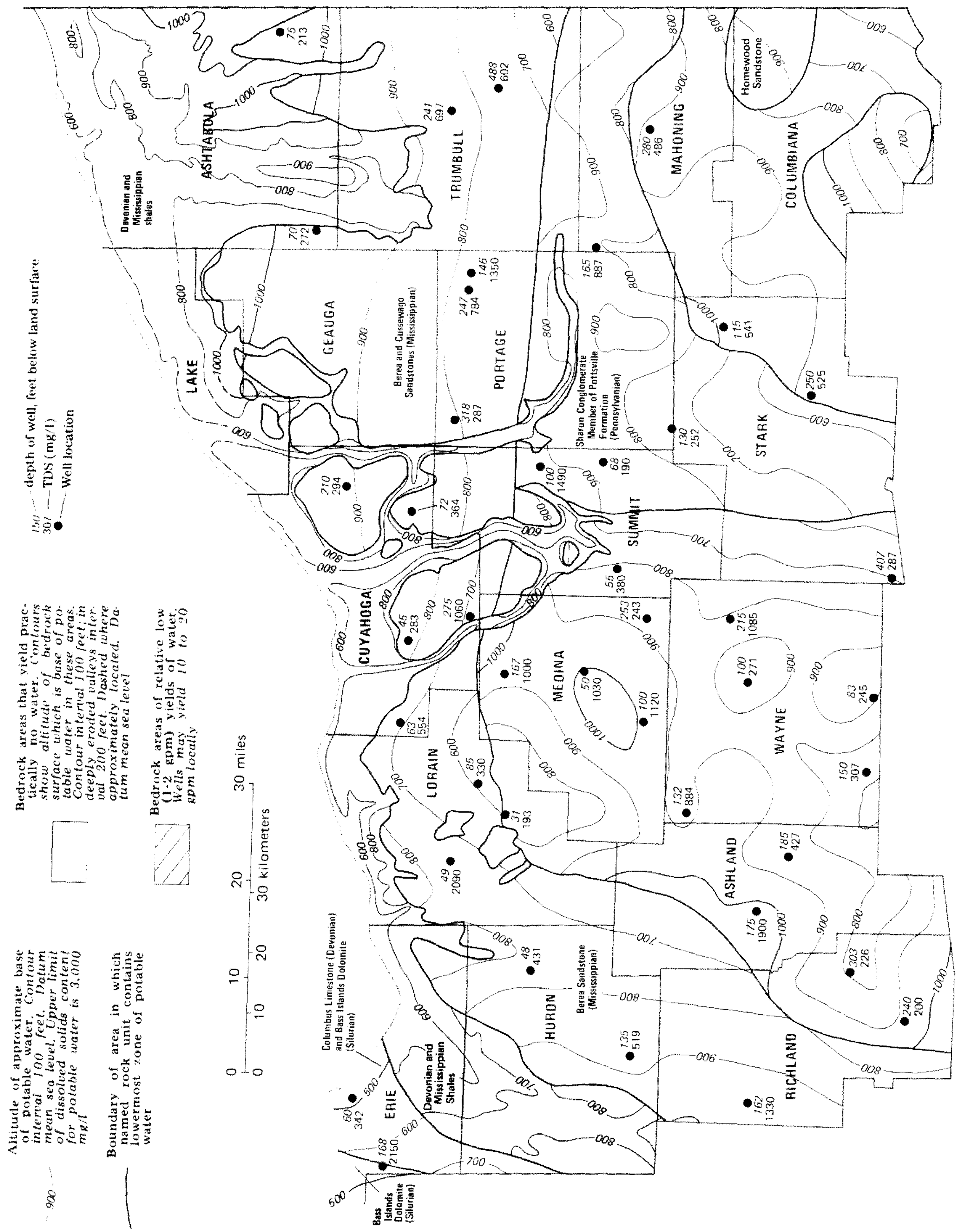
Stout, Lamborn, and Schaaf (1932, p. 48-49) presented chemical analyses of two brine samples obtained from a well penetrating both the "Big Injun" and the Berea at the Coal Ridge Salt Company at Pomeroy, Meigs County. One sample was obtained by W. J. Root about 1888 (102,070 mg/l TDS) and the other by C. W. Foulk about 1905 (105,198 mg/l TDS). Active salt-plant operations at Pomeroy were reported as recently as 1974 (Ohio Department of Industrial Relations, 1975, p. 121). Environmental considerations eventually resulted in the closing of the brining operations at Pomeroy. Stout, Lamborn, and Schaaf also reported analyses of "Big Injun" brines from Marion Township, Noble County (165,360 mg/l TDS), and Jackson Township, Monroe County (119,950 mg/l TDS).

Only one formation-water sample as concentrated as the brines formerly produced at Pomeroy was obtained in this study. This sample (no. 112—122,700 mg/l TDS) was obtained from the eastern sandstone body ("Maxton") in Center Township, Guernsey County. Brines of equal or greater concentration can be expected south of this well in Guernsey County. Brines of a similar concentration also might be encountered in easternmost Muskingum County, although the sandstone in this area is thin and discontinuous and not conducive to development of high-capacity disposal wells.

Although natural brines are sufficiently concentrated in much of southeastern Ohio to make exploitation economically feasible, artificial brines are a more attractive source of sodium chloride. Artificial brines, produced by dissolving halite deposits with injected fresh water, are more concentrated and contain far fewer impurities than natural brines. No natural brines presently are evaporated to produce salt in Ohio. Room-and-pillar mining of rock salt and artificial brining now account for all of Ohio's salt production.

Fresh water

The "Big Injun" sandstone in westernmost Coshocton and westernmost Muskingum Counties contains fresh water. The depth to this aquifer, because of topography, is variable, but generally increases eastward owing to regional dip and,


Altitude of approximate base of potable water. Contour interval 100 feet. Datum mean sea level. Upper limit of dissolved solids content for potable water is 3,000 mg/l
Boundary of area in which named rock unit contains lowermost zone of potable water
Bedrock areas that yield practically no water. Contours show altitude of bedrock surface which is base of potable water in these areas. Contour interval 100 feet; in deeply eroded valleys interval 200 feet. Dashed where approximately located. Datum mean sea level
Bedrock areas of relative low (1-2 gpm) yields of water. Wells may yield 10 to 20 gpm locally
150 — depth of well, feet below land surface
301 — TDS (mg/l)
Well location
0 10 20 30 miles
0 10 20 30 kilometers
ASHTABULA
TRUMBULL
MAHONING
COLUMBIANA
LAKE
GEAUGA
PORTAGE
STARK
CUYAHOGA
SUMMIT
MEDINA
WAYNE
LORAIN
ASHLAND
ERIE
HURON
RICHLAND
Devonian and Mississippian shales
Berea and Cussewago Sandstones (Mississippian)
Sharon Conglomerate Member of Pottsville Formation (Pennsylvanian)
Homewood Sandstone
Columbus Limestone (Devonian) and Bass Islands Dolomite (Silurian)
Bass Islands Dolomite (Silurian)
Devonian and Mississippian Shales
Berea Sandstone (Mississippian)

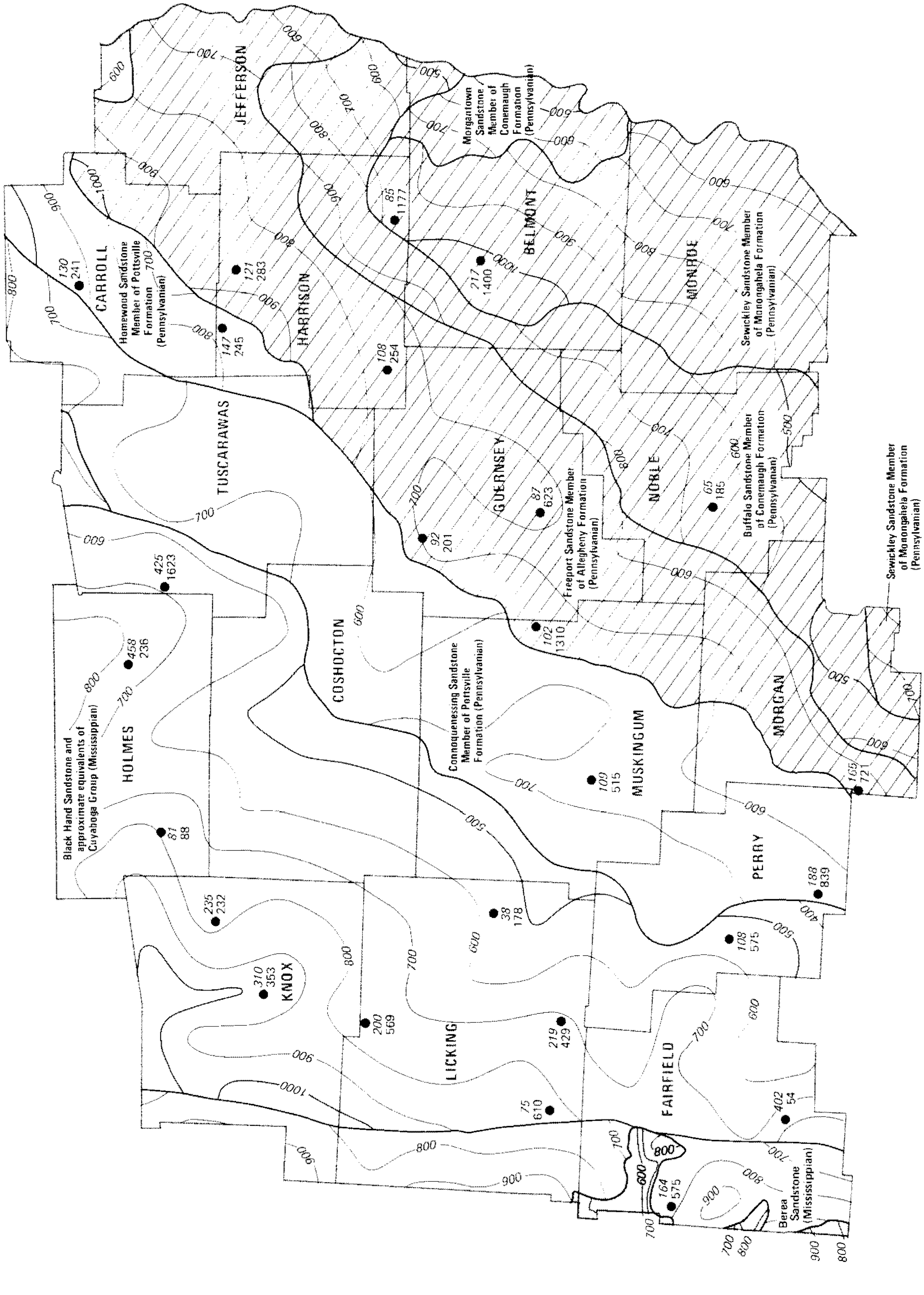


FIGURE 12.—Elevation of the approximate base of potable water in part of eastern Ohio (modified from Sedam and Stein, 1970).

except in major stream valleys, exceeds 200 feet in most places. Although it is an important aquifer west of the study area, the "Big Injun" generally is not developed as a water supply in Coshocton or Muskingum County because of its depth. However, where water supplies cannot be obtained in shallower aquifers, the "Big Injun" is a fairly reliable source of potable water. Fresh water has been reported in the "Big Injun" at depths as great as 500 feet. The approximate downdip limit of potable water in the "Big Injun," based on a limited number of formation-water samples, is shown on plate 6. Detailed hydrologic investigations are needed to locate the fresh-water/brackish-water interface more accurately.

EVALUATION OF THE STUDY AREA FOR BRINE DISPOSAL

The State of Ohio has taken steps to regulate the disposal of oil-field brines. The Underground Injection Control (UIC) Section of the Ohio Division of Oil and Gas was established in 1978 to review and approve all plans for subsurface brine disposal. New rules for the Underground Injection Control Program became effective June 1, 1982. These rules, which cover the construction, operation, and reporting of conditions involving disposal wells, were developed in cooperation with and were approved by representatives of the Ohio Oil and Gas Association. The recommendations in this report should not be construed as official policy of the State of Ohio. An operator investigating the possibility of a brine-disposal well in the potential injection area shown on plate 6 should first consult the UIC Section of the Division of Oil and Gas.

Western sandstone body

In general, water quality in the western sandstone body has been safeguarded by effective casing programs. Where the "Big Injun" sandstone is greater than 50 feet thick and is porous and permeable, it is thought to contain fresh or brackish water. Its importance as a source of potable water, and as a potential source of treatable brackish water, precludes use of the western sandstone body for disposal of produced brines.

West-central part of study area

The rock units in the area separating the eastern and western sandstone bodies, whether correlative to the "Big Injun" or to the "Maxton," generally contain less than 50 feet of "clean" sandstone. Lack of adequate reservoir, therefore, in most places eliminates these units from consideration as potential injection horizons. An additional disqualification is that formation water within these rocks is thought to be brackish or potable in most of the area. There appear to be a few localities (in central Muskingum County, for instance) where the salinity of the formation water is likely to exceed that of normal sea water (35,000 mg/l TDS), and minimal injectivity requirements might be met. As a practical matter, however, it is unlikely that these areas would or should be utilized for brine injection because the position of the brackish-water/brine interface is not known precisely and reservoir injectivity could be expected to be marginal, at best. In addition, the proximity of much more attractive injection sites in southern Guernsey County and possibly Noble and Morgan Counties should all but eliminate this area from consideration.

Eastern sandstone body

Part of the eastern sandstone body in southern Guernsey County appears to be suitable for oil-field-brine disposal (pl. 6). Although no injection-test results are known to the author, wells which encounter more than 100 feet of sandstone should have adequate capacity to service several "average" "Clinton" wells. Where reservoir conditions permit, lesser sandstone thicknesses also may provide adequate injectivity.

Sparse borehole-geophysical-log control in the potential injection area at the time this study was conducted makes additional geologic evaluation an important prerequisite to selecting an injection site. Seemingly erratic changes in lithology and rapid variations in sandstone thickness underscore the importance of maintaining accurate drillers' logs and of running borehole geophysical logs whenever possible.

The formation-water investigation indicates that within the potential injection area shown on plate 6, "Maxton" formation waters will have chloride-ion and TDS concentrations greater than those found in sea water. The potential injection area is located well south of the interpreted brackish-water/brine interface because of uncertainty regarding the exact position of the interface, and in order to provide a buffer zone for potentially treatable brackish water.

According to Sedam and Stein (1970), the Sharon (drillers' "Maxton") is a source of fresh water in parts of six counties in northeastern Ohio (fig. 12). Disposal of concentrated brines within the potential injection area will increase the concentration of total dissolved solids in the formation waters of the injection horizon and cause a northward migration of isocon lines. Risk of endangerment to public or private water supplies and to potential brackish-water resources as a result of oil-field-brine injection appears to be minimal in the near future because of the distance involved relative to the slow rate of fluid movement in the subsurface.

The long-term effects of brine disposal in shallow aquifers unfortunately are not easily predicted because they depend on a number of variables, including, but not limited to, the number and location of injection wells, the volume and concentration of injected brines, the rate and direction of ground-water circulation, and the rates of recharge to and withdrawal from the aquifer system. Other important variables are areal extent and thickness of the disposal horizon, which, together with effective pore volume and irreducible water saturation, basically define the reservoir storage capacity. Buildup of reservoir pressure and effects of fluid migration increase with decreasing storage capacity. Although difficult to assess, the long-term effects of injection are important considerations as population growth and industrial development increase the demand for adequate supplies of potable water.

Perhaps the greatest risk to water supplies posed by a brine-injection program is the possibility of vertical migration of injected brines. Vertical migration could occur as a result of poor disposal-well construction, through nearby improperly plugged wells, or as a result of hydrologic communication of the injection horizon with overlying aquifers. Potential problems stemming from the proximity of improperly plugged wells or due to improper well construction or design should be identified during the required permit-application procedure. Direct communication of the injection horizon with overlying aquifers has not been indicated by available borehole geophysical logs. Thus, as long as shallow disposal wells do not encounter natural vertical-fracture systems and are not allowed to be fractured, the potential for vertical migration appears to be minimal in the proposed injection area.

Preliminary investigation south of the study area indicates that the eastern sandstone body continues on trend. Because depth to the injection horizon increases to the south, the potential for vertical migration is even less in this direction and additional or more attractive injection sites in Noble and Morgan Counties, and possibly in Washington County, are a likelihood.

Although it may not be an ideal solution to the problem, brine injection in the proposed area in most cases would be preferable to the current practice of annular disposal because it would present less risk of endangerment of water resources. Even so, periodic monitoring of observation wells in the brackish-water zone to detect increased salinity levels should be included in any comprehensive shallow disposal program. Long-term stability of the chemical quality of formation-water samples could be used to document the environmental safety of this disposal method. However, significant and systematic deterioration of water quality that would ultimately affect the safety of public or private water supplies would mandate discontinuance of brine injection.

Substantial expenditures for drilling, completions, and equipment are required to initiate a brine-injection program. As long as annular injection remains an accepted practice, little incentive to implement a more costly method of disposal is anticipated. The purpose of this investigation is not to advocate shallow disposal of produced brines, but rather to assess the geologic feasibility of this practice in a specific area. Several other alternatives to annular disposal are available. These include deep injection, reinjection, utilization of the brine as a raw material, utilization for ice and dust control, and curtailment of marginal petroleum-producing operations. Assessment of the practicality, economic feasibility, environmental impact, and other factors ultimately will decide the method of disposal.

CONCLUSIONS AND RECOMMENDATIONS

The drillers' term "Big Injun" has been used incorrectly to designate one or more sandstone units of Pennsylvanian age. Within the study area, two geologically and hydrologically separate sandstone systems have been identified and mapped. A preliminary study of formation-water quality reinforces the geological interpretation. Water quality decreases with increasing depth and distance from the respective recharge areas rather than simply in an easterly direction as would be expected on the basis of previous interpretations.

The informal name "Big Injun" is properly applied to the western sandstone body defined in this study. Because of its importance as a source of potable and potentially treatable brackish water, the western sandstone body is not suitable for oil-field-brine disposal and should continue to be protected by properly designed casing programs. The eastern sandstone body defined in this study is believed to be the subsurface equivalent of the Pennsylvanian-age Sharon sandstone (drillers' "Maxton"). Available formation-water analyses indicate that the "Maxton" should be protected in the northern part of the study area, but that an area in southern Guernsey County may be suitable for oil-field-brine injection. Additional and perhaps more suitable sites for brine injection are thought to be located south of the study area in parts of Noble, Morgan, and possibly Washington Counties.

The sandstone units of similar stratigraphic position in the area separating the eastern and western sandstone bodies generally are not considered to be sufficiently thick for effective brine disposal. Also, little is known about the formation-water chemistry of these units.

Additional research is needed, particularly in the area thought to be suitable for brine injection, and on trend to the south. A better understanding of the complex stratigraphic relationships exhibited by the sandstone units at and near the Pennsylvanian-Mississippian unconformity could be achieved by a re-examination of previous correlations in light of the present findings.

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APPENDIX.—SUMMARY OF WELL-LOG DATA

ABBREVIATIONS

CS	*casing*	NL	*not logged*
DF	*derrick floor*	Q	*quarter of township*
E	*estimated*	RT	*rotary table*
KB	*Kelly bushing*	WH	*well head*

Township	Land subdivision	Permit no.	Operator	Well no. and name	Reference elevation (ft above sea level)	Depth (ft) to top of Berea	Depth (ft) to top of "Big Injun"	Depth (ft) to base of "Big Injun"	Net thickness (ft) of "clean" "Big Injun"
COSHOCTON COUNTY									
Adams	Lot 19, 2Q	2159	Columbia	Garber 11363	1053 DF	1065	473	639	12
Adams	Sec. 3	2297	Moore	Maurer 20077	1015 KB	1031	425	584	37
Bedford	Lot 16	2253	Moore	1 O'Bryon	1042 DF	1044	426	NL	56
Bedford	Sec. 7	1456	Natol	1 Gilmore	1086 DF	1022	447	633	56
Bedford	Sec. 7	1203	Natl. Assoc. Petroleum	1 Gilmore	1067 DF	995	419	603	43
Bedford	Sec. 15	2390	Callander & Kimbrel/Giant	1 Groves	1098 KB	1041	467	632	41
Bedford	Sec. 15	2385	Callander & Kimbrel	1-A Mikesell	1063 KB	1003	429	610E	42
Bedford	Sec. 25	2351	Callander & Kimbrel	1 Kanuckle	1024 KB	948	376	557	67
Bedford	Sec. 25	2465	Callander & Kimbrel	2 Kanuckle	1012 DF	943	384	555	23
Bethlehem	2Q	525	National	1 Conrad	814 DF	797	202	397	67
Bethlehem	2Q	2074	Oxford	1 Pope	842 DF	862	268	448	40
Bethlehem	Lot 12, 3Q	2167	Columbia	1-A Hedrick	1005 KB	1023	436	619	50
Clark	1Q	1427	Pure	2 Patterson	1023 KB	890	NL	483	?
Clark	1Q	1388	Campbell	1 Van Buren	927 DF	870	255	472	82
Clark	Lot 1, 2Q	1727	Midwest	1-C Reed	798 DF	743	124	354	69
Clark	Lot 2, 2Q	1719	Midwest	1-C Foreman	912 DF	855	242	467	55
Clark	Lot 3, 2Q	1857	Midwest	2 Eppley	853 DF	793	182	406	77
Clark	Lot 14, 2Q	1793	Midwest	1 Scheibe	853 DF	778	167	392	83
Clark	Sec. 12	1435	Admiral	1-C Badertscher	1007 DF	952	350	543	61
Clark	Sec. 13	1401	Natol	2 Mullet	982 DF	916	302	531	70
Clark	Sec. 14	1235	Patten	1 Croup	798 DF	726	110	324	63
Clark	Sec. 17	1386	Natol	1 Williamson	830 DF	724	128	340	67
Clark	Sec. 17	1399	Natol	2 Young	992 DF	937	338	538	64
Clark	Sec. 24	1466	Natol	2 McNeal	796 DF	757	152	357	57
Clark	Sec. 24	1470	Natol	7 Williamson	780 DF	747	130	347	81
Crawford	Lot 1, 1Q	2333	Moore	1 Glenn-Fisher-Smith	1055 KB	1058	446E	NL	46+
Crawford	Lot 3, 1Q	2326	Moore	1 Schlegel	1025 KB	969	NL	538	6+
Crawford	Lot 15, 1Q	2331	Moore	1 Wilson-Armbrust	1015 KB	1083	475	NL	50+
Crawford	Sec. 4	1825	Kin-Ark	1 Cox	1201 KB	1146	535	728	44
Crawford	Sec. 11	2332	Moore	1 Limbacher	968 KB	966	361	530	45
Crawford	Sec. 11	2329	Moore	1 Schumaker	1128 KB	1110	512	NL	17+
Crawford	Sec. 17	2177	Redman	1 Herman	1191 KB	1135	532	712	35
Crawford	Sec. 20	2330	Moore	2 Limbacher	1018 KB	996	374E	564	42+
Crawford	Sec. 20	2343	Moore	2 Lorenz	1069 KB	1073	463	NL	28+
Crawford	Sec. 20	2339	Moore	1 Thomas-Lorenz	998 KB	997	396	567	36
Crawford	Sec. 21	2327	Moore	1 Lorenz-Parrillo	990 KB	995	NL	540	?
Franklin	2Q	2020	Quaker State	1 BSA, Muskingum Valley Council	860 DF	1007	448	628	40
Jackson	Lot 2, 2Q	2171	Cyclops	3 Roemer	1055 KB	1155	555	753	50
Jackson	Lot 3, 2Q	2194	Cyclops	1 Miskimen	759 RT	836	242	435	40
Jackson	Lot 9, 2Q	2417	Cyclops	3-B Montgomery	1011 DF	1077	477E	NL	68
Jackson	Lot 10, 2Q	2277	Cyclops	1 Montgomery	982 KB	1065	466	663	37
Jackson	Lot 10, 2Q	2415	Cyclops	2-B Montgomery	1000 DF	1064	466	661	51
Jackson	Sec. 1	2216	Cyclops	1 Bailey	801 RT	877	279	476	64
Jackson	Sec. 7	1269	Arrowhead	1 Foster	856 DF	880	295	475	34
Jackson	Sec. 9	2375	Cyclops	1 Olinger	800 DF	845	247	NL	46
Jackson	Sec. 10	2271	Cyclops	3 Montgomery	960 DF	1048	452	645	34
Jackson	Sec. 10	2244	Cyclops	1 Montgomery	848 RT	928	333	534	50

APPENDIX.—SUMMARY OF WELL-LOG DATA—Continued

Township	Land subdivision	Permit no.	Operator	Well no. and name	Reference elevation (ft above sea level)	Depth (ft) to top of Berea	Depth (ft) to top of "Big Injun"	Depth (ft) to base of "Big Injun"	Net thickness (ft) of "clean" "Big Injun"
COSHOCTON COUNTY (continued)									
Jefferson	Lot 1, 4Q	2053	Tatum	1 Lee	1040 KB	1033	444	632	42
Jefferson	Lot 3, 4Q	2179	Moore	Lee 11427	970 DF	936	368	NL	34
Jefferson	Lot 20, 4Q	2150	Columbia	Foster 11342	808 KB	748	162	351	35
Keene	Lot 11, 2Q	1225	Sanders	1 Lowery	797 DF	812	210	408	39
Keene	Lot 15, 4Q	880	Roberson-Beisser	1 Geib	809 DF	860	262	450	14
Keene	Lot 15, 4Q	2131	Management	1 Wilson-Hunter	817 KB	881	280	464	22
Keene	Lot 17, 4Q	1024	Roberson	1 Boyd	832 DF	867	263	446	8
Keene	Sec. 8	2130	Columbia	Wood 11299	957 KB	1008	401	596	44
Lafayette	1Q	2309	Moore	1 Taylor	811 KB	802	NL	393	0+
Lafayette	Lot 2, 4Q	2262	Moore	1 Evans	950 KB	921	363	523	13
Lafayette	Lot 2, 4Q	2260	Moore	1 Hormetz-Bluck	849 KB	841	279	433	16
Lafayette	Lot 2, 4Q	2198	Moore	Porteus 11480	910 KB	892	327	NL	11
Lafayette	Lot 3, 4Q	2164	Columbia	Porteus 11372	827 KB	819	234	419	3
Lafayette	Lot 3, 4Q	2197	Moore	Porteus 11479	830 KB	801	235E	397	20+
Lafayette	Lot 4, 4Q	2212	Moore	Bluck 11381	988 KB	997	415	NL	46
Lafayette	Lot 4, 4Q	2220	Moore	Bluck 11398	812 KB	828	268	429	11
Lafayette	Lot 4, 4Q	2185	Moore	Bluck 11473	818 KB	830	272	436	4
Lafayette	Lot 4, 4Q	2186	Moore	Noble 11474	825 KB	824	267	426	0
Lafayette	Lot 5, 4Q	2323	Moore	Conley 20102	815 KB	845	NL	452	0+
Lafayette	Lot 5, 4Q	2251	Moore	1 Noble	885 KB	894	335	493	8
Lafayette	Lot 5, 4Q	2250	Moore	1 Shurtz	818 KB	839	NL	441	0+
Lafayette	Lot 6, 4Q	2240	Moore	1 Frye	938 KB	973	406	570E	28
Lafayette	Lot 6, 4Q	2263	Moore	1 Waggoner	843 KB	875	NL	466	0+
Lafayette	Lot 7, 4Q	2217	Moore	Taylor 11393	950 KB	986	415	NL	30
Lafayette	Lot 8, 4Q	2319	Moore	1 McCleary	831 KB	850	280E	452	9+
Linton	Lot 28	2243	Columbia	CSOE 11472	810 KB	901	336	518	32
Linton	Sec. 1	2237	Moore	1 Baird	910 KB	939	360E	543	0+
Linton	Sec. 1	2239	Moore	4 Frye	790 KB	813	NL	419	0+
Linton	Sec. 1	2249	Moore	1 Shurtz-Bradford	818 KB	849	276E	453	16+
Linton	Sec. 1	2247	Moore	1 Wiggins	798 KB	838	NL	442	0+
Linton	Sec. 2	2248	Moore	1 Frye	790 KB	843	270E	449	0+
Linton	Sec. 2	2238	Moore	3 Frye	777 KB	820	NL	423	0+
Linton	Sec. 8	2214	Columbia	CSOE 11470	819 KB	888	304	498	12
Linton	Sec. 16	2219	Columbia	CSOE 11471	898 KB	1058	500	682	15
Mill Creek	Lot 5	2168	Columbia	Karr 11378	1062 KB	1043	435	621	61
Mill Creek	Sec. 4	1390	Oxford	2 Bechtol	992 DF	924	316	504	79
Mill Creek	Sec. 10	1257	Natl. Assoc. Petroleum	2 Lower	865 KB	794	141	357	76
Monroe	Lot 11	1382	Weed	1 Smith	1062 DF	938	339	573	60
Monroe	Lot 11	1364	Weed	1 Stockli	1110 DF	991	393	630	60
Monroe	Lot 23	1439	Natol	1 Hawkins	1202 DF	1063	467	702	54
Monroe	Lot 24	1452	Natol	2 Taylor	1214 DF	1072	486	714	57
Monroe	Lot 24	1471	Natol	4 Taylor	1262 DF	1126	526	766	65
Monroe	Lot 26	1421	Oxford	1 Dunham	1077 DF	934	350	568	82
Monroe	Lot 27	1443	Natol	1 Kanuckle	917 DF	769	180	408	74
Monroe	Lot 32	1330	Natol	1 Johnson	1129 DF	1008	426	646	64
Monroe	Sec. 2	1259	Tedrow	2 Randles	1007 DF	853	266	477	40
Monroe	Sec. 8	932	Mammoth	1 Snow	864 DF	739	157	368	54
Monroe	Sec. 9	1258	Campbell	2 Nicholl	975 DF	868	267	487	70
Monroe	Sec. 13	1008	Mammoth	2 Snow heirs	946 DF	805	220	435	53
Monroe	Sec. 22	1402	Natol	1 Giauque	1065 DF	1012	419	613	59
Newcastle	Lot 1, 1Q	2157	Jadoil	2 MWCD	982 DF	715	132	352	44
Newcastle	Lot 1, 1Q	2201	Jadoil	3 MWCD	1146 DF	992	416	630	57
Newcastle	Lot 1, 1Q	2182	Jadoil	4 MWCD	962 DF	815	240	454	59
Newcastle	Lot 17, 1Q	2085	Jadoil	1-A Young	982 DF	793	221	410	84
Newcastle	Lot 17, 2Q	1449	Rixleben	1 MWCD	835 DF	596	NL	232	15+
Newcastle	Lot 18, 2Q	1756	Chase	1 Chase	1001 DF	746	151	388	62
Oxford	1Q	2188	Moore	Hoobler 11476	822 KB	892	321	NL	30
Oxford	1Q	2318	Moore	1 Sharrock-Pollock	808 KB	881	NL	472	12+
Oxford	2Q	2355	Moore	Rivers-Gress-Schlarb 20071	928 KB	945	NL	534	0+
Oxford	2Q	2393	Moore	Waters 20083	800 KB	854	NL	441	7+

APPENDIX.—SUMMARY OF WELL-LOG DATA—Continued

Township	Land subdivision	Permit no.	Operator	Well no. and name	Reference elevation (ft above sea level)	Depth (ft) to top of Berea	Depth (ft) to top of "Big Injun"	Depth (ft) to base of "Big Injun"	Net thickness (ft) of "clean" "Big Injun"
COSHOCTON COUNTY (continued)									
Oxford	Lot 1, 3Q	2347	Moore	1 Apple	939 KB	947	385	543	18
Oxford	Lot 1, 3Q	2371	Moore	Apple-Herbert 20070	919 KB	922	NL	517	0+
Oxford	Lot 1, 3Q	2408	Moore	Sharrock 20069	843 KB	830	NL	423	0+
Oxford	Lot 5W, 3Q	2346	Moore	2 Rehard	858 KB	846	NL	448E	0+
Perry	Sec. 6	1002	Bears	1 Rine	1122 DF	918	333	530	87
Perry	Sec. 7	1321	Nye	1 Crowther	1088 DF	907	320	514	52
Perry	Sec. 7	1005	Bears	1 Mayberry	1046 DF	894	305	499	104
Perry	Sec. 7	1075	Bears	2 Mayberry	1104 DF	938	350	544	63
Perry	Sec. 7	1294	Clinton	6 Taylor	1032 DF	854	271	470	47
Perry	Sec. 8	1065	Bears	1 Conrad	1077 DF	941	362	548	28
Perry	Sec. 8	1238	Dunnill	3 Shuy	974 DF	838	252	450	79
Perry	Sec. 8	1334	Dunnill	4 Shuy	1072 DF	915	325	525	48
Perry	Sec. 11	2363	Callander & Kimbrel/Giant	1 Ashcraft	1139 KB	1047	478	655	33
Perry	Sec. 11	2361	Callander & Kimbrel/Giant	1 Mikesell	1118 KB	1038	474	650	30
Perry	Sec. 12	2400	Callander & Kimbrel/Giant	1 Mercer	1109 KB	1018	447	NL	29+
Perry	Sec. 13	1100	Bears	1-B Conrad	1062 DF	917	350	554	32
Perry	Sec. 16	974	Preston	1 McCamment	1154 DF	978	370	594	94
Perry	Sec. 21	2352	Callander & Kimbrel/Giant	1 Underwood	894 KB	809	NL	409	36+
Pike	Sec. 2	2413	Callander & Kimbrel/Giant	1-A Mikesell	988 KB	892	NL	510	10+
Pike	Sec. 6	1450	Natol	1 Gault	816 DF	621	53E	247	147+
Pike	Sec. 12	1781	Basore	2 Lake	953 DF	878	309	494	134
Pike	Sec. 13	1929	Petroleum Energy	1-A Gardner	1071 DF	968	351	600	222
Pike	Sec. 23	1348	Bears	1 McKee	932 DF	832	258	452	100
Tiverton	Sec. 8	1379	Bears	1-A Day	1018 DF	817	232	432	78
Tiverton	Sec. 9	1224	Grady	1 Hays	976 DF	757	170	367	121
Tiverton	Sec. 19	2435	Elkhead	1 Conkle	1097 DF	904	328	495	?
Tiverton	Sec. 22	1061	Disbennet	1 Fox	1037 DF	873	302	487	109
Virginia	Lot 21, 4Q	2183	Gallagher	1 McLeod heirs	800 KB	912	358	510	36
Virginia	Lot 23, 4Q	2144	Gallagher	1 Hunt	870 KB	954	402	553	30
Washington	Sec. 8	2166	Collins	1 Thomas	957 DF	958	378	559	49
White Eyes	Lot 11, 1Q	2145	Columbia	Opportunity Ranch 11352	965 KB	970	375	545	30
White Eyes	Sec. 3	2153	Wright	1 Schumaker	1038 DF	1006	408	584	20
White Eyes	Sec. 3	2151	Wright	2 Schumaker	968 DF	944	339	512	28
White Eyes	Sec. 3	2152	Wright	3 Schumaker	917 DF	888	292	468	23
GUERNSEY COUNTY									
Adams	Sec. 8	958	Turrill	1 Wells	1167 KB	1368	847	972	11
Adams	Sec. 12	1176	Hammerstone	1 Wells	991 KB	1202	667	808	0
Adams	Sec. 15	782	Lakeshore	1 Marshall	1007 KB	1220	707	838	31
Adams	Sec. 16	1455	Titan	1 Morton	1005 KB	1259	747	878	21
Cambridge	Lot 2, 3Q	1824	Cyclops	1 Smith	809 KB	1031	453	640	128
Cambridge	Sec. 3N	1482	Tatum	1-A Kemp	820 DF	1047	416	647	194
Cambridge	Sec. 4S	777	McCullough	1 Cameron	1061 DF	1248	617	845	108
Cambridge	Sec. 22	1305	Southern Triangle	1 Bennett	960 KB	1208	604	803	137
Cambridge	Sec. 25	1322	Big Piney	2 Zinc	925 KB	1126	564	743	42
Jackson	Lot 19	1418	Tri-Coast	1 Cambridge Country Club	913 KB	1244	610	860	180
Jackson	Sec. 6E	1454	McClellan	1 Minarchek	918 KB	1221	628	831	63
Jackson	Sec. 6E	1840	Enterprise	1 Nicholson	835 KB	1140	527	745	80
Jackson	Sec. 11	1826	Enterprise	1 Bartholow-Rossiter	807 KB	1122	518	733	63
Jackson	Sec. 11	1828	Enterprise	2 Bartholow-Rossiter	807 KB	1131	565	744	71
Jackson	Sec. 20	1836	Enterprise	3 Bartholow-Rossiter	848 KB	1166	572	781	51
Jackson	Sec. 20	1813	Enterprise	1 Dyer	906 DF	1210	618	820	135
Jackson	Sec. 25	852	Ridge	1 Koval	1040 KB	1398	833	1005	9
Knox	Sec. 6	1627	Shakespeare	1 Warner	1074 KB	1217	667	814	24
Knox	Sec. 9	1221	Natl. Treasure Mines	1 Miller	958 KB	1106	555	724	31
Knox	Sec. 19	1672	Appalachian	1 Koch	1026 KB	1132	592	723	20
Knox	Sec. 19	1684	Appalachian	1 Neilley	966 KB	1127	576	725	32
Liberty	Sec. 7	1588	Donoco	1 Weber	824 KB	1016	386	602	105
Liberty	Sec. 13	1187	Guernsey	1 Robertson	788 KB	1024	387	621	187

APPENDIX.—SUMMARY OF WELL-LOG DATA—Continued

Township	Land subdivision	Permit no.	Operator	Well no. and name	Reference elevation (ft above sea level)	Depth (ft) to top of Berea	Depth (ft) to top of "Big Injun"	Depth (ft) to base of "Big Injun"	Net thickness (ft) of "clean" "Big Injun"
GUERNSEY COUNTY (continued)									
Madison	Sec. 1	1811	Mammoth	1 Hayes	1133 KB	1395	886	1019	0
Madison	Sec. 7	1731	Mammoth	1 Stutz	892 DF	1150	664	759	40
Madison	Sec. 8	917	Turrill	1 Bennett	1040 KB	1318	804	937	54
Monroe	Sec. 4	1260	Baumgartner	1 Hill	1048 KB	1196	664	811	103
Monroe	Sec. 18	1232	Chief	1 Larrick	1088 KB	1283	NL	901	86+
Richland	2Q	971	Southern Triangle	1 Potts	840 KB	1248	712	845	68
Richland	Sec. 1	1406	East Ohio	1 Booher	838 KB	1274	740	886	29
Richland	Sec. 20	979	Southern Triangle	1 Smith	912 KB	1328	773	926	59
Spencer	Sec. 5	877	Refiners	1 Keilitz	1001 KB	1395	824	1016	19
Spencer	Sec. 5	823	Stocker & Sitler	1 Keith	952 DF	1343	781	962	35
Spencer	Sec. 6	1823	Enterprise	1 Reed	928 KB	1362	811	990	14
Spencer	Sec. 6	1853	Enterprise	2 Reed	958 KB	1378	827	1010	25
Spencer	Sec. 6	1858	Enterprise	3 Reed	944 KB	1354	803	984	21
Spencer	Sec. 6	426-A	Duchscherer	2 Watson	969 DF	1360	804	993	39
Spencer	Sec. 7	1863	Enterprise	1 Cooper	1074 KB	1537	983	1170	28
Spencer	Sec. 7	1862	Enterprise	2 Cooper	1059 KB	1527	986	1162	21
Spencer	Sec. 8	843	Dever	1 Bay	1074 DF	1533	974	1165	52
Spencer	Sec. 9	888	Refiners	1 Keilitz-Baker	1008 KB	1415	850	1040	25
Spencer	Sec. 9	862	Refiners	1 Brissey	1019 KB	1438	879	1063	14
Spencer	Sec. 9	885	Refiners	2 Brissey	1049 KB	1459	898	1088	27
Spencer	Sec. 9	1335	Stocker & Sitler/White Shield	1 Flesher	998 KB	1426	874	1044	5
Spencer	Sec. 9	1848	Enterprise	1 Kinkade	945 KB	1377	817	996	7
Spencer	Sec. 10	1201	Stocker & Sitler/White Shield	1 Goette	930 KB	1325	766	928	3
Spencer	Sec. 10	1200	Stocker & Sitler/White Shield	2 Goette	860 KB	1247	688	852	6
Spencer	Sec. 10	1334	Stocker & Sitler/White Shield	1 LePage	883 KB	1247	651	851	44
Spencer	Sec. 15	1677	Enterprise	2 Bear-Moorhead	987 KB	1394	817	1005	24
Spencer	Sec. 15	1676	Enterprise	3 Bear-Moorhead	923 KB	1327	754	933	16
Spencer	Sec. 15	1695	Enterprise	4 Bear-Moorhead	965 KB	1386	807	993	32
Spencer	Sec. 15	1822	Enterprise	6 Bear-Moorhead	908 KB	1332	756	938	30
Spencer	Sec. 15	1844	Enterprise	7 Bear-Moorhead	965 KB	1374	801	986	18
Spencer	Sec. 15	1608	Enterprise	1 Jenkins-LePage	978 KB	1374	802	983	36
Spencer	Sec. 15	1668	Enterprise	2 Jenkins-LePage	958 KB	1378	810	993	38
Spencer	Sec. 15	1678	Enterprise	3 Jenkins-LePage	993 KB	1412	838	1028	36
Spencer	Sec. 15	1796	Enterprise	5 Jenkins-LePage	950 KB	1360	785	968	48
Spencer	Sec. 15	1691	Enterprise	5 Lestock-Howell	872 KB	1314	742	926	46
Spencer	Sec. 15	1845	Enterprise	9 Lestock-Howell	940 KB	1372	795	981	23
Spencer	Sec. 16	1679	Enterprise	4 Jenkins-LePage	971 KB	1388	793	1012	42
Spencer	Sec. 16	1837	Enterprise	6 Jenkins-LePage	927 KB	1363	772	987	35
Spencer	Sec. 16	1838	Enterprise	8 Jenkins-LePage	934 KB	1365	762	988	6
Spencer	Sec. 16	1610	Enterprise	1 Lestock-Howell	852 KB	1285	716	897	30
Spencer	Sec. 16	1669	Enterprise	2 Lestock-Howell	841 KB	1287	727	910	12
Spencer	Sec. 16	1675	Enterprise	3 Lestock-Howell	846 KB	1299	740	921	7
Spencer	Sec. 16	1670	Enterprise	4 Lestock-Howell	862 KB	1336	777	961	6
Spencer	Sec. 16	1798	Enterprise	6 Lestock-Howell	873 KB	1335	774	954	8
Spencer	Sec. 16	1799	Enterprise	7 Lestock-Howell	842 KB	1289	722	903	25
Spencer	Sec. 16	1800	Enterprise	8 Lestock-Howell	858 KB	1306	756	927	66
Spencer	Sec. 17	1699	Enterprise	1 Palmer-Voytko	961 KB	1431	895	1067	14
Spencer	Sec. 20	1336	Stocker & Sitler/White Shield	1 Monroe	899 KB	1412	885	1049	8
Spencer	Sec. 21	1639	Enterprise	1 Cowgill-Howell	999 KB	1468	909	1100	11
Spencer	Sec 21	1674	Enterprise	2 Cowgill-Howell	1059 KB	1538	980	1173	17
Spencer	Sec. 21	1692	Enterprise	3 Cowgill-Howell	928 KB	1398	830	1021	37
Spencer	Sec. 21	1702	Enterprise	4 Cowgill-Howell	922 KB	1376	819	990	86
Spencer	Sec. 21	1797	Enterprise	5 Cowgill-Howell	888 KB	1359	827	992	15
Spencer	Sec. 21	1820	Enterprise	6 Cowgill-Howell	998 KB	1466	932	1098	22
Spencer	Sec. 21	1839	Enterprise	8 Cowgill-Howell	833 KB	1291	740	910	59
Spencer	Sec. 21	1611	Enterprise	1 Dougherty-Frazier	957 KB	1462	907	1095	0
Spencer	Sec. 21	1694	Enterprise	2 Dougherty-Frazier	976 KB	1469	912	1102	6
Spencer	Sec. 21	1821	Enterprise	3 Dougherty-Frazier	903 KB	1392	826	1013	34

APPENDIX.—SUMMARY OF WELL-LOG DATA—Continued

Township	Land subdivision	Permit no.	Operator	Well no. and name	Reference elevation (ft above sea level)	Depth (ft) to top of Berea	Depth (ft) to top of "Big Injun"	Depth (ft) to base of "Big Injun"	Net thickness (ft) of "clean" "Big Injun"
GUERNSEY COUNTY (continued)									
Spencer	Sec. 21	1723	Enterprise	2 Dudley-May	925 KB	1411	845	1031	43
Spencer	Sec. 22	1202	Stocker & Sitler/White Shield	3 Moorhead	860 KB	1289	733	904	32
Spencer	Sec. 22	1711	Enterprise	1 Taylor-Carpenter	974 KB	1376	813	988	9
Spencer	Sec. 22	1735	Enterprise	2 Taylor-Carpenter	880 KB	1307	750	923	24
Spencer	Sec. 26	1332	Stocker & Sitler/White Shield	1 Cowgill	1008 KB	1434	883	1046	2
Spencer	Sec. 26	1378	Stocker & Sitler	1 Kackley	997 RT	1417	860	1033	23
Spencer	Sec. 28	1700	Enterprise	1 Wilson-Schwarz	843 KB	1354	795	973	7
Spencer	Sec. 29	1631	Enterprise	1 Martin	980 KB	1557	1018	1200	0
Spencer	Sec. 32	1615	Enterprise	1 Millhone	925 RT	1491	946	1133	17
Spencer	Sec. 33	1710	Enterprise	1 Rayner	848 KB	1408	853	1044	46
Spencer	Sec. 34	1377	Stocker & Sitler	1 Harding	999 RT	1482	921	1111	68
Spencer	Sec. 35	1333	Stocker & Sitler/White Shield	1 Wickham	990 KB	1419	845	1029	166
Spencer	Sec. 36	925	Western	1 Keaton	824 KB	1259	682	892	139
Valley	Sec. 1	1459	Red Hawk	1 Heskett	955 DF	1271	667	886	159
Valley	Sec. 7	1632	Enterprise	1 Morse	838 KB	1163	558	789	209
Valley	Sec. 14	1606	Enterprise	1 Bear-Moorhead	824 KB	1212	658	819	12
Valley	Sec. 14	1795	Enterprise	5 Bear-Moorhead	870 KB	1235	681	844	12
Valley	Sec. 14	1097	Stocker & Sitler	1 Moorhead	840 KB	1207	634	791	28
Valley	Sec. 14	1098	Stocker & Sitler	2 Moorhead	830 KB	1215	589	799	31
Valley	Sec. 24S	1827	Enterprise	2 Sakach	889 DF	1274	632	847	174
Washington	Sec. 5	1564	Turrill	1 Colley	1156 KB	1307	760	956	177
Washington	Sec. 7	1565	Turrill	1 Hughs-Gingerich	1036 KB	1186	638	812	101
Washington	Sec. 15	1603	Petrox	1 Hashman	1005 RT	1205	681	854	138
Washington	Sec. 15	1629	Petrox	2 Hashman	990 RT	1195	651	822	155
Westland	2Q	977	MB	1 Mallett	981 KB	1316	776	943	31
Westland	3Q	840	Liberty	1 Gordon	1017 DF	1385	827	1017	11
Westland	3Q	1517	Towner	1 Nicholson	849 RT	1231	706	860	10
Westland	Sec. 9	1160	National	1 Scott	934 KB	1212	661	827	18
Westland	Sec. 12	842	Black River	1 Deselm	1056 DF	1338	788	958	23
Westland	Sec. 13	1161	National	1 Blackstone	905 KB	1200	660	824	19
Westland	Sec. 18	834	Black River	1 Aitken	1065 DF	1393	833	1012	30
Westland	Sec. 19	845	Black River	1 Hayes	1014 DF	1311	736	937	66
Westland	Sec. 19	833	Black River	1 Marshall	1068 KB	1373	815	998	18
Westland	Sec. 19	830	Dever	1 Mitchell	1068 DF	1387	831	1009	53
Westland	Sec. 22	831	Black River	1 McManaway-Vessels	1055 KB	1388	825	1009	15
Westland	Sec. 23	824	Dever	1 Foulk	1063 DF	1415	832	1037	23
Westland	Sec. 23	838	Duchscherer	1 Marlatt	1086 KB	1440	877	1066	15
Westland	Sec. 23	829	Duchscherer	3 Watson	1044 DF	1410	844	1032	7
Wheeling	Sec. 14	1363	Ohio Fuel	1 Wagner-Davis-Nay	862 KB	1012	346	636	224
Wheeling	Sec. 19E	844	Black River	1 Fieldson	1074 KB	1255	636	875	117
Wills	2Q	1074	Westrans	1 Cunningham	934 KB	1351	784	948	98
Wills	Sec. 3S	984	Pointer	1 Henderson-Knowlton	871 KB	1318	757	931	84
MUSKINGUM COUNTY									
Adams	Sec. 13	2159	Quaker State	1 Radcliffe	1037 KB	1229	687	866	14
Adams	Sec. 18	2481	Pemco	2 Fliger	991 DF	1194	651	822	21
Adams	Sec. 18	2110	Quaker State	1 Mozena	1007 KB	1196	652	826	14
Adams	Sec. 18	2010	Duchscherer	1 Rasor	1003 DF	1194	658	820	33
Adams	Sec. 19	2023	Duchscherer	2 Leist	1017 DF	1206	682	838	27
Adams	Sec. 20	2161	Quaker State	1 Bell	1051 KB	1262	738	896	16
Adams	Sec. 20	2024	Duchscherer	1 Leist	1098 KB	1337	813	974	19
Adams	Sec. 21	2014	Ridge	1 Durant	956 KB	1181	662	824	11
Adams	Sec. 22	2005	Ridge	1 Bradford	1022 KB	1218	688	854	15
Adams	Sec. 23	2022	Duchscherer	2 Rasor	1079 KB	1286	758	925	24
Adams	Sec. 23	2203	Quaker State	1 Vernon	994 KB	1207	673	838	28
Adams	Sec. 24	2202	Quaker State	1 Leasure	948 KB	1135	602	766	26
Blue Rock	Sec. 2	1911	Petroc	3-A Wilkins	781 DF	1216	675	856	22
Blue Rock	Sec. 11	3105	Quaker State	1 Frame	1060 RT	1490	959	1131	12
Blue Rock	Sec. 11	2310	Quaker State	1 Wilson	932 DF	1367	836	1007	30
Blue Rock	Sec. 15	3099	Quaker State	1 Dearinger	950 KB	1359	836	1000	38

APPENDIX.—SUMMARY OF WELL-LOG DATA—Continued

Township	Land subdivision	Permit no.	Operator	Well no. and name	Reference elevation (ft above sea level)	Depth (ft) to top of Berea	Depth (ft) to top of "Big Injun"	Depth (ft) to base of "Big Injun"	Net thickness (ft) of "clean" "Big Injun"
MUSKINGUM COUNTY (continued)									
Blue Rock	Sec. 16	3014	Quaker State	1 Snyder	973 DF	1388	869	1030	33
Blue Rock	Sec. 16	906	Quaker State	1 Lyon-Levison-Hardeson	929 DF	1298	783	962	37
Blue Rock	Sec. 21	3117	Quaker State	1 Fox	729 KB	1118	590	766	24
Blue Rock	Sec. 26	3295	Chief	1 Frame-Sutton	943 DF	1414	900	1056	11
Blue Rock	Sec. 26	3372	Chief	2 Frame-Sutton	1031 DF	1502	990	1144	17
Blue Rock	Sec. 26	3410	Chief	3 Frame-Sutton	1047 DF	1525	1010	1168	0
Blue Rock	Sec. 29	2018	P.G. & F.	1 Gale	965 DF	1353	831	998	21
Blue Rock	Sec. 34	2046	Quaker State	1 Daw	1051 KB	1478	962	1122	27
Blue Rock	Sec. 34	3077	Quaker State	2 Daw	1031 KB	1464	943	1109	25
Blue Rock	Sec. 34	3093	Quaker State	1 Miller	1039 KB	1465	948	1109	26
Blue Rock	Sec. 35	3092	Quaker State	1 Mitchell	1024 KB	1477	964	1122	22
Cass	2Q, T3, R7	2567	Lynn	1 Cox	726 DF	797	238	381	38
Cass	Sec. 4	1629	Jebb	1 Robinson	903 DF	913	363	511	53
Highland	Sec. 4	2358	Quaker State	1 Brown	926 DF	1182	679	823	14
Highland	Sec. 4	2364	Quaker State	2 Brown	820 DF	1074	573	721	7
Highland	Sec. 4	2097	Quaker State	1 Sandel	918 KB	1160	651	796	9
Highland	Sec. 6	3297	Johnston	1 Funk	1016 KB	1320	814	960	17
Highland	Sec. 7	2572	Westland	1 Caldwell	923 DF	1186	681	819	12
Highland	Sec. 7	2538	Westland	1 Cooper	902 RT	1180	675	817	15
Highland	Sec. 7	2536	Westland	1 Shroyer	842 KB	1109	604	746	11
Highland	Sec. 8	2532	Westland	1 Ruby	831 KB	1105	589	738	0
Highland	Sec. 11	2526	Tatum	1 McQuain	1082 DF	1340	825	NL	16
Highland	Sec. 14	2525	Westland	1 Switzer	1068 KB	1358	856	995	5
Highland	Sec. 15	2337	Farrar	1 Balderson	978 DF	1259	713	900	34
Highland	Sec. 16	2718	Liberty	1 Knicely	1002 DF	1273	723	914	34
Highland	Sec. 16	2853	Liberty	2 Knicely	967 DF	1255	706	900	35
Highland	Sec. 16	2135	Quaker State	1 Lake	988 KB	1288	748	931	42
Highland	Sec. 18	3282	Johnston	1 McCormick	1049 KB	1348	845	985	14
Highland	Sec. 19	3245	Bingham	5 Hanna	990 KB	1305	801	NL	23
Highland	Sec. 24	3284	Johnston	1 Lake	1017 KB	1327	790	971	42
Hopewell	Lot 5, 1Q	1680	Natol	1 Clements	857 DF	844	253	469	133
Hopewell	Lot 7, 1Q	1681	Natol	2 Miller	814 WH	786	192	413	139
Hopewell	Sec. 3N	1623	Oxford	4 Shepler	869 DF	834	280	472	76
Hopewell	Sec. 3S	1559	Winn	1 Perine	1023 DF	1001	441	651	164
Jackson	Lot 5,1Q	1589	Bears	1 Ashcraft	781 DF	672	103	290	83
Jackson	Lot 11, 1Q	1960	Hunting	1-A Miller	812 DF	767	198	362	50
Jackson	Sec. 6	1580	Jebb	1 Phillips	907 DF	737	122	354	221
Jackson	Sec. 6	1587	Jebb	2 Phillips	861 DF	702	95	321	219
Jackson	Sec. 16	2232	Kentucky	1 Randall-Baughman	862 DF	708	100	337	196
Jackson	Sec. 16	3348	Kentucky	2 Randall-Baughman	852 DF	698	85	325	223
Jackson	Sec. 23	1963	Shrider	1 Lentz	797 DF	718	150	335	68
Jackson	Sec. 25	3034	Kentucky	1 Heisey	872 DF	713	108	351	209
Jackson	Sec. 25	3347	Kentucky	1 Van Voorhis	791 DF	660	50	288	228
Licking	4Q	1570	Natl. Assoc. Petroleum	1 Mattingly	855 DF	812	243	436	112
Meigs	Sec. 27	2903	Fortune	1 Prouty	1105 KB	1710	1201	1337	14
Meigs	Sec. 33	2929	Fortune	1 White	986 KB	1547	1036	1180	18
Monroe	Lot 1	2120	Quaker State	1 McCormick	818 KB	1042	512	674	42
Monroe	Lot 2	2194	Quaker State	2 McCormick	967 KB	1194	665	823	19
Monroe	Lot 16	2063	Marks	1 Barr	812 KB	1037	526	671	7
Monroe	Lot 30	2160	Quaker State	1 Mercer	840 KB	1054	535	689	17
Monroe	Lot 34	2792	Liberty	1 Berry	837 DF	1060	539	696	27
Monroe	Lot 37	2162	Quaker State	1 Matchett	918 KB	1129	608	764	13
Monroe	Sec. 23	2591	Eastern	1 Castor-Muse	804 DF	1034	510	653	2
Muskingum	2Q, T2, R7	2348	Irvin	1 Linhardt	817 DF	907	373	532	21
Newton	Sec. 23E	2050	Oxford	1 Fraunfelter	922 DF	1073	543	703	23
Newton	Sec. 26W	2059	Oxford	1 Skinner	902 DF	918	343	583	240
Newton	Sec. 29	2218	Dusty	3 Ohio Power	963 DF	1051	NL	706	57+
Newton	Sec. 31	1855	Mershon-Rainbow	1-A Ohio Power	927 DF	1029	445	680	226
Newton	Sec. 32	2219	Dusty	2 Ohio Power	863 DF	958	NL	620	58+

APPENDIX.—SUMMARY OF WELL-LOG DATA—Continued

Township	Land subdivision	Permit no.	Operator	Well no. and name	Reference elevation (ft above sea level)	Depth (ft) to top of Berea	Depth (ft) to top of "Big Injun"	Depth (ft) to base of "Big Injun"	Net thickness (ft) of "clean" "Big Injun"
MUSKINGUM COUNTY (continued)									
Perry	Sec. 3	1584	Worldwide	1 Grear	942 DF	1183	685	823	28
Perry	Sec. 4	1636	Pennoco	1 Hina	852 DF	1098	568	744	45
Perry	Sec. 4	1657	Barco	1 Ross	941 DF	1185	657	830	37
Perry	Sec. 19	1648	Kewanee	1 Mikolojcik	951 DF	1255	737	906	29
Perry	Sec. 21	1699	Harris	1 Smitley	844 DF	1170	664	824	17
Rich Hill	Sec. 21	2592	Eastern	1 Schell-Warne	883 DF	1371	903	1013	6
Rich Hill	Sec. 36	2915	Guernsey	36-C Ohio Power	915 KB	1476	1018	1129	7
Salem	Lot 5	3262	Johnston	2 Watson	945 KB	1205	712	842	5
Salem	Lot 6	3263	Johnston	1 Watson	1037 KB	1281	786	916	1
Salem	Lot 24	2673	Westland	1 Shirer	1026 KB	1265	751	901	11
Salem	Lot 34	3118	Johnston	1 Kreis	949 KB	1171	648	809	13
Salem	Lot 36	3264	Johnston	1 Lowry	987 KB	1201	668	844	11
Salem	Sec. 6	3266	Johnston	2 Best	1016 KB	1199	668	832	28
Salem	Sec. 7	2906	Johnston	1 Gierke-Roberts	989 KB	1184	650	820	28
Salem	Sec. 8	2908	Johnston	1 Darner-Stiers	987 DF	1216	672	853	28
Salem	Sec. 8	3070	Johnston	1 Knicely	993 DF	1199	657	833	26
Salem	Sec. 13	2907	Johnston	1 Caldwell	962 DF	1176	630	815	32
Salem	Sec. 14	2909	Johnston	1 French-McNeish	922 DF	1144	611	782	33
Salem	Sec. 18	3269	Johnston	1 Heil	983 DF	1209	685	850	20
Salem	Sec. 18	3041	Johnston	1 Knipe	942 DF	1171	637	813	29
Salem	Sec. 19	2923	Jadoil	1-A Dunlap	961 DF	1214	689	855	23
Salem	Sec. 22	3030	Jadoil	1-A Johnson-Markey	972 DF	1240	706	881	12
Salem	Sec. 22	3134	Jadoil	2-B Johnson-Markey	952 DF	1204	675	845	10
Salem	Sec. 23	1617	Barco	1-B Winegardner	925 DF	1169	634	812	31
Salt Creek	Sec. 22	945	National	1 U.S.A. Stackhouse	970 CS	1330	820	985	4
Salt Creek	Sec. 26	2604	Oxford	1 Kelso	922 DF	1321	809	958	14
Springfield	Sec. 17	3368	Johnston	1 Sullivan	931 KB	979	NL	629	54
Union	Lot 11	2243	Guernsey	1 Parks	942 DF	1343	799	977	42
Union	Lot 23	2028	Cole	1 Patton	1086 DF	1510	977	1153	48
Union	Sec. 1	2254	Tip Top	1 Muskingum College	978 KB	1300	752	927	18
Union	Sec. 10	2039	Muskingum Development	1 Fee	937 KB	1298	769	932	49
Union	Sec. 13	1640	Barco	1 Tenney	990 DF	1370	841	1016	22
Union	Sec. 14	1593	Worldwide	1 Hill	902 DF	1264	737	909	22
Washington	Lot 2, 3Q, T1, R7	2641	Jadoil	1-A Swingle	902 DF	1076	556	717	17
Washington	Lot 2, 3Q, T1, R7	2924	Jadoil	1-A Wagner-Michel	892 DF	1055	534	693	15
Washington	Lot 4, 3Q, T1, R7	2795	Jadoil	1-A Redman	912 DF	1052	534	689	27
Washington	Lot 4, 3Q, T1, R7	2861	Jadoil	2-B Redman	921 DF	1059	536	697	42
Washington	4Q, T1, R7	3031	Jadoil	2 Hildebrand	871 DF	1060	540	701	18
Washington	4Q, T1, R7	2980	Jadoil	3-P Redman	892 DF	1053	528	700	20
Washington	4Q, T1, R7	2845	Jadoil	1-A Walker-Jividen	882 DF	1062	543	705	11
Washington	Sec. 2	2888	Jadoil	1-A Culbertson	902 DF	1065	539	697	38
TUSCARAWAS COUNTY									
Bucks	Sec. 6	2277	Moore	2 Goedel	1079 KB	1042	460	606	42
Bucks	Sec. 13	2263	Moore	Stauffer 20081	1245 KB	1238	649	795	18
Bucks	Sec. 15	2274	Moore	1 Lund	1114 KB	1085	489	NL	39
Bucks	Sec. 15	2276	Moore	1 Toland	1073 KB	1028	454	594	39
Bucks	Sec. 16	1766	Columbia	Regula 11301	934 KB	921	302	483	49
Bucks	Sec. 16	2271	Moore	1 Warren	1010 KB	1012	430E	556	0+
Bucks	Sec. 16	2275	Moore	1 Warren-Toland	1000 KB	993	410E	564	0+
Bucks	Sec. 22	2261	Moore	Winkelman-Cline 20080	1035 KB	1044	NL	629	8+
Clay	Lot 5, Gnadenhutten Tr.	2050	Stocker & Sitler	2 Water Street Realty	841 RT	856	335	494	154
Clay	Lot 6, Gnadenhutten Tr.	1634	Stocker & Sitler	2 Kinsey	885 RT	898	374	520	135
Clay	Lot 7, Gnadenhutten Tr.	1404	Appalachian	3 Ross Clay Products	1158 KB	1162	612	780	158
Clay	Lot 8, Gnadenhutten Tr.	1627	Stocker & Sitler	1 Frey	893 RT	876	340	490	78
Clay	Lot 9, Gnadenhutten Tr.	1632	Stocker & Sitler	2 Frey	1125 RT	1105	582	718	108
Clay	Lot 11, Gnadenhutten Tr.	1402	Appalachian	1 DeVore	845 KB	808	287	426	95
Clay	Lot 11, Gnadenhutten Tr.	1400	Appalachian	2 DeVore	902 KB	874	347	490	96
Clay	Lot 11, Gnadenhutten Tr.	2115	Stocker & Sitler	2 Hoffman	833 RT	804	290	418	124
Clay	Lot 13, Gnadenhutten Tr.	1401	Appalachian	1 Ross Clay Products	841 KB	812	283	430	123

APPENDIX.—SUMMARY OF WELL-LOG DATA—Continued

Township	Land subdivision	Permit no.	Operator	Well no. and name	Reference elevation (ft above sea level)	Depth (ft) to top of Berea	Depth (ft) to top of "Big Injun"	Depth (ft) to base of "Big Injun"	Net thickness (ft) of "clean" "Big Injun"
TUSCARAWAS COUNTY (continued)									
Clay	Lot 14, Gnadenhutten Tr.	1403	Appalachian	2 Ross Clay Products	936 KB	958	430	572	124
Clay	Lot 17, Gnadenhutten Tr.	2036	Stocker & Sitler	1 Shull	828 RT	850	333	478	188
Clay	Lot 23, Gnadenhutten Tr.	1495	Stocker & Sitler	1 Gooding	1100 RT	1139	538	760	177
Clay	Lot 24, Gnadenhutten Tr.	1496	Stocker & Sitler	2 Gooding	868 RT	924	320	545	217
Clay	Lot 28, Gnadenhutten Tr.	2035	Stocker & Sitler	1 Hoffman	833 RT	830	311	450	117
Clay	Lot 30, Gnadenhutten Tr.	2114	Stocker & Sitler	3 Hoffman	833 RT	808	287	430	137
Clay	Lot 2, 1Q	1493	Stocker & Sitler	1 Glauser	1130 RT	1188	597	811	167
Clay	Lot 6, 1Q	1497	Stocker & Sitler	1 Gooding	900 RT	943	354	562	208
Clay	Lot 35, 2Q	2022	Stocker & Sitler	2 Larson	900 RT	906	374	523	149
Clay	Lot 12, 3Q, T6, R2	2042	Stocker & Sitler	1 Enos	1150 RT	1200	636	820	150
Clay	Sec. 19	1376	Stocker & Sitler	3 Allgyer	1139 RT	1122	507	732	215
Clay	Sec. 19	2043	Stocker & Sitler	1 Waterford	1080 RT	1117	529	734	139
Clay	Sec. 20	1375	Stocker & Sitler	2 Allgyer	1034 RT	1067	479	690	200
Clay	Sec. 20	1377	Stocker & Sitler	4 Allgyer	993 RT	999	432	624	170
Clay	Sec. 20	958	Stocker & Sitler	2-B Harding	925 DF	952	388E	626	155
Clay	Sec. 21	1374	Stocker & Sitler	1 Allgyer	984 RT	990	431	618	144
Clay	Sec. 21	1313	Stocker & Sitler	1 Decker	1258 KB	1284	699	911	191
Clay	Sec. 21	1172	Stocker & Sitler	1 Kadri	1050 KB	1084	477	711	184
Clay	Sec. 21	1173	Stocker & Sitler	1 Taylor	1270 KB	1286	720	924	138
Clay	Sec. 22	1321	Stocker & Sitler	1 Gambs	1119 RT	1160	560	790	167
Clay	Sec. 22	1311	Stocker & Sitler	1 Harding	1090 KB	1153	574	783	109
Clay	Sec. 22	1267	Stocker & Sitler	1 Hughes	1159 KB	1202	612	828	172
Clay	Lot 4, 3Q, T7, R2	1066	Midterra	1 Jarvis-Kerns	1126 KB	1102	495	718	216
Clay	Lot 7, 3Q, T7, R2	965	Stocker & Sitler	1 Keffer	997 KB	982	453	600	143
Clay	Lot 9, 3Q, T7, R2	1629	Stocker & Sitler	4 Schreiner	950 RT	948	386	563	166
Clay	Lot 13, 3Q, T7, R2	963	Stocker & Sitler	3 Mizer	1020 KB	980	443	597	154
Clay	Lot 14, 3Q, T7, R2	955	Stocker & Sitler	1 Mizer	1161 KB	1108	575	726	137
Clay	Lot 15, 3Q, T7, R2	1070	Midterra	1 Keffer	1116 KB	1080	478	695	143
Clay	Lot 17, 3Q, T7, R2	1076	Midland	1 Miller	927 KB	880	280	492	144
Clay	Lot 18, 3Q, T7, R2	1630	Stocker & Sitler	3 Schreiner	960 RT	942	408	563	147
Clay	Lot 20, 3Q, T7, R2	1628	Stocker & Sitler	2 Schreiner	990 RT	962	426	576	94
Clay	Lot 22, 3Q, T7, R2	1648	Stocker & Sitler	1 Cross Creek Coal	967 RT	986	412	603	141
Clay	Lot 22, 3Q, T7, R2	1705	Stocker & Sitler	3 Cross Creek Coal	1117 RT	1072	507	689	145
Clay	Lot 25, 3Q, T7, R2	1304	Stocker & Sitler	1 Feller	1194 KB	1112	542	734	177
Clay	Lot 28, 3Q, T7, R2	1625	Stocker & Sitler	2 Cross Creek Coal	925 RT	892	339	511	120
Clay	Lot 29, 3Q, T7, R2	1631	Stocker & Sitler	1 Schreiner	950 RT	928	382	546	115
Clay	Lot 25, 4Q, T7, R2	1626	Stocker & Sitler	1 Kinsey	885 RT	894	361	505	123
Clay	Lot 26, 4Q, T7, R2	1288	Stocker & Sitler	1 Kohler	952 KB	926	401	542	140
Clay	Lot 27, 4Q, T7, R2	1633	Stocker & Sitler	1 Horsfall	928 RT	930	404	585	181
Clay	Lot 29, 4Q, T7, R2	1717	Stocker & Sitler	1 Kinsey	1016 RT	1035	483	658	168
Clay	Lot 30, 4Q, T7, R2	1301	Stocker & Sitler	1 Myers	980 KB	995	457	615	157
Jefferson	Lot 30, 3Q	1750	Stocker & Sitler	1 Kuhn	1051 RT	1063	599	680	58
Jefferson	Lot 31, 3Q	1965	Stocker & Sitler	2 Leonhard	1030 RT	1024	567	641	44
Jefferson	Lot 33, 3Q	1299	Stocker & Sitler	1 Hendricks	1180 KB	1103	555	722	59
Jefferson	Lot 36, 3Q	1234	East Ohio	1 Haglock	1075 KB	1023	569	644	39
Jefferson	Lot 37, 3Q	1966	Stocker & Sitler	1 Leonhard	1246 RT	1214	756	834	27
Jefferson	Lot 2, 1Q	1265	Stocker & Sitler	1 Rice	943 KB	852	391	477	43
Jefferson	Lot 14, 1Q	1976	Stocker & Sitler	2 Gasser	960 RT	896	433	504	36
Jefferson	Lot 14, 1Q	1211	East Ohio	1 Warner	989 KB	918	454	524	15
Jefferson	Lot 15, 1Q	1302	Stocker & Sitler	2 Rice	1150 KB	1076	608	693	51
Jefferson	Lot 20, 1Q	1981	Stocker & Sitler	1 Gasser	1102 RT	1025	558	630	41
Jefferson	Lot 35, 1Q	1986	Stocker & Sitler	3 Sauser	988 RT	926	466	547	59
Jefferson	Sec. 11	1993	Stocker & Sitler	1 Sauser	1166 RT	1136	677	754	20
Jefferson	Sec. 11	1977	Stocker & Sitler	2 Sauser	948 RT	877	416	503	22
Jefferson	Sec. 12	1111	Stocker & Sitler	1 Moss	1116 KB	1082	623	691	15
Jefferson	Sec. 17	1241	Western	1 Wherley-Lorenz	1012 KB	986	519	591	26
Jefferson	Sec. 18	1124	East Ohio	1 Lorenz	1073 KB	1059	596	662	46
Jefferson	Sec. 18	1501	Westland	1 Ridenour	966 KB	937	468	548	52
Jefferson	Sec. 18	1515	Westland	1 Wherley-Ridenour	1144 KB	1113	649	719	60
Jefferson	Sec. 18	1110	East Ohio	1 Urfer-Brick	1003 KB	980	523	588	38
Jefferson	Sec. 19	1969	Stocker & Sitler	1 Avon	1105 RT	1103	649	714	4

APPENDIX.—SUMMARY OF WELL-LOG DATA—Continued

Township	Land subdivision	Permit no.	Operator	Well no. and name	Reference elevation (ft above sea level)	Depth (ft) to top of Berea	Depth (ft) to top of "Big Injun"	Depth (ft) to base of "Big Injun"	Net thickness (ft) of "clean" "Big Injun"
TUSCARAWAS COUNTY (continued)									
Jefferson	Sec. 19	1994	Stocker & Sitler	1 Burrier	1145 RT	1114	651	735	38
Jefferson	Sec. 19	1036	Quaker State	1 Brokaw	1105 KB	1070	530	677	111+
Jefferson	Sec. 20	1971	Stocker & Sitler	2 Avon	1122 RT	1123	667	745	39
Jefferson	Sec. 20	1970	Stocker & Sitler	3 Avon	1095 RT	1080	621	701	30
Jefferson	Sec. 20	1978	Stocker & Sitler	2 Burrier	985 RT	961	503	576	27
Jefferson	Sec. 20	1985	Stocker & Sitler	3 Burrier	1140 RT	1093	634	707	18
Jefferson	Sec. 21	1979	Stocker & Sitler	1 Kinsey	1107 RT	1112	641	726	64
Jefferson	Sec. 21	1980	Stocker & Sitler	1 Wires	1167 RT	1166	732	782	34
Jefferson	Sec. 21	1983	Stocker & Sitler	2 Wires	1207 RT	1204	740	818	44
Jefferson	Sec. 21	1984	Stocker & Sitler	3 Wires	1067 RT	1074	616	698	53
Jefferson	Sec. 22	1075	Quaker State	1 Buss-Schupp	1165 KB	1153	686	758	47
Jefferson	Sec. 22	1982	Stocker & Sitler	1 Myers	1132 RT	1144	676	765	76
Jefferson	Sec. 23	1218	Western	1 Kandel-Sherrett	1155 KB	1169	703	780	30
Jefferson	Sec. 23	1196	Western	1 Wallace-Green	1084 KB	1087	616	707	43
Mill	Lot 9, Rathbone Tr.	1463	Collins	1 Anderson	868 DF	877	438	534	38
Mill	Lot 10, Rathbone Tr.	1644	Appalachian	1 Arnold	854 KB	860	411	467	29
Mill	Lot 11, Rathbone Tr.	1230	Collins/Carter-Jones	1 Wright	890 DF	897	456	557	49
Mill	Lot 12, Rathbone Tr.	1232	Collins/Carter-Jones	1 Shipton	923 DF	940	502	599	25
Mill	Lot 9, Spencer Tr.	1624	Appalachian	1 Everhard	1152 KB	1176	728	795	16
Mill	Lot 11, Spencer Tr.	1398	Appalachian	1 Everhard-Midvale Coal	1023 KB	1030	620	648	1
Mill	Lot 12, Spencer Tr.	1137	Gundy	1 Gundy	945 KB	930	490	549	12
Mill	Lot 12, Spencer Tr.	1161	Stocker & Sitler	1 Gundy	962 KB	966	548	587	11
Mill	Lot 14, Spencer Tr.	1363	Appalachian	3 Gundy	856 KB	872	420	490	54
Mill	Lot 15, Spencer Tr.	1362	Appalachian	2 Gundy	877 KB	878	462	495	0
Mill	Lot 15, Spencer Tr.	1394	Appalachian	2 Simpson	846 KB	888	437	539	19
Mill	Lot 19, Speneer Tr.	1612	Appalachian	1 Garner	1090 KB	1120	688	738	0
Mill	Lot 19, Spencer Tr.	1583	Appalachian	3 U.S. Concrete Pipe	908 KB	942	524	566	0
Mill	Lot 20, Spencer Tr.	1408	Wiser	1 Pancher-Space	910 RT	937	502	554	2
Mill	Lot 21, Spencer Tr.	1587	Appalachian	2 U.S. Concrete Pipe	930 KB	965	523	590	0
Mill	Lot 24, Spencer Tr.	1589	Appalachian	1 U.S. Concrete Pipe	888 KB	915	482	531	9
Mill	Lot 27, Spencer Tr.	1442	Wiser	1 Bender	872 RT	891	454	506	3
Mill	Uhrichsville Tr.	1588	Appalachian	1 Wallace	878 KB	890	456	509	12
Mill	Sec. 22	1701	Collins	1 Single	1172 KB	1321	868	967	82
Mill	Sec. 22	1896	Collins	1 Starkey-Hillyer	924 KB	1072	640	709	40
Mill	Sec. 24	1483	Collins	1 Johns	1151 KB	1265	828	916	26
Mill	Sec. 24	1663	Clinton	1 Miracle	1085 RT	1262	808	905	58
Mill	Sec. 28	1700	Collins	1 Insley	897 KB	1031	597	681	50
Mill	Sec. 29	1617	Collins	1 Duso	1153 KB	1260	818	908	65
Mill	Sec. 29	1477	Collins	1 Galbreath	1031 KB	1150	738	796	32
Mill	Sec. 31	1909	Zenith	1 Penn Central	868 RT	902	456	566	15
Mill	Sec. 33	1712	Stocker & Sitler	2 Murphy	875 RT	948	530	585	34
Mill	Sec. 33	1713	Stocker & Sitler	3 Murphy	868 RT	960	541	599	32
Mill	Sec. 34	1711	Stocker & Sitler	1 Murphy	890 RT	980	549	622	13
Mill	Sec. 34	1699	Collins	1 Wright-Insley	907 KB	1033	604	683	36
Mill	Sec. 35	1702	Stocker & Sitler	2 Delong	970 RT	1100	661	752	52
Mill	Sec. 35	1744	Stocker & Sitler	1 Lehigh	966 RT	1044	604	695	13
Mill	Sec. 35	1709	Stocker & Sitler	1 Wolfe	948 RT	1081	641	730	18
Mill	Sec. 36	1703	Stocker & Sitler	1 Delong	1138 RT	1207	767	857	35
Mill	Sec. 36	1645	Appalachian	1 Phillips	902 KB	982	553	630	15
Oxford	Sec. 20	1192	Everley & Assoc.	1 King	928 KB	1032	412	650	192
Perry	Sec. 3	2046	Enterprise	1 Chandler	910 RT	1043	544	674	115
Perry	Sec. 4	1650	Northeast	1 Helter-Shull-Coventry	920 RT	1035	398	660	242
Perry	Sec. 4	2102	Enterprise	1 Stout	953 RT	1054	427	677	229
Perry	Sec. 5	1610	Northeast	1 Drevon-Owens	982 RT	1078	NL	706	141+
Perry	Sec. 5	1585	Stocker & Sitler	2 Morrison	1239 RT	1304	742	904	143
Perry	Sec. 6	1455	Stocker & Sitler	1 Gray	1260 RT	1340	721	1002	270
Perry	Sec. 6	1458	Stocker & Sitler	2 Gray	1237 RT	1306	683	938	254
Perry	Sec. 6	1456	Stocker & Sitler	3 Gray	1210 RT	1273	668	913	240
Perry	Sec. 6	1457	Stocker & Sitler	4 Gray	1088 RT	1179	572	826	254
Perry	Sec. 7	2111	Enterprise	1 Rogers	1240 RT	1336	732	1013	275

APPENDIX.—SUMMARY OF WELL-LOG DATA—Continued

Township	Land subdivision	Permit no.	Operator	Well no. and name	Reference elevation (ft above sea level)	Depth (ft) to top of Berea	Depth (ft) to top of "Big Injun"	Depth (ft) to base of "Big Injun"	Net thickness (ft) of "clean" "Big Injun"
TUSCARAWAS COUNTY (continued)									
Perry	Sec. 14	2143	Enterprise	1 Dickinson	1210 DF	1324	783	950	141
Perry	Sec. 15	1488	Stocker & Sitler	1 Hayden	1130 RT	1220	644	852	208
Perry	Sec. 15	1487	Stocker & Sitler	2 Hayden	1108 RT	1187	646	836	186
Perry	Sec. 15	1489	Stocker & Sitler	3 Hayden	1120 RT	1243	718	878	160
Perry	Sec. 15	1486	Stocker & Sitler	4 Hayden	1220 RT	1312	756	1007	247
Perry	Sec. 20	890	Kin-Ark	1 Fitzgerald	1201 DF	1395	959	1022	30
Perry	Sec. 23	2041	Stocker & Sitler	1 Nalle	1245 RT	1404	846	1038	28
Perry	Sec. 23	2040	Stocker & Sitler	2 Nalle	1208 RT	1371	828	1001	21
Perry	Sec. 24	2039	Stocker & Sitler	1 Kidd	1210 RT	1340	805	976	137
Perry	Sec. 24	2038	Stocker & Sitler	2 Kidd	1195 RT	1352	817	986	80
Perry	Sec. 25	2440	Shakespeare	1 Houser	1190 KB	1302	770	933	139
Rush	Lot 4	1755	Collins	1 Edwards	968 KB	1000	483	627	59
Rush	Lot 6	1754	Collins	2 Page	988 KB	1072	492	693	105
Rush	Lot 15	1893	Collins	1 Page	1038 KB	1078	537	697	124
Rush	Lot 21	1677	Stocker & Sitler	1 Edwards	1160 RT	1241	663	868	190
Rush	Lot 26	1679	Stocker & Sitler	1 White	897 RT	933	398	593	146
Rush	Lot 27	1680	Stocker & Sitler	2 White	1057 RT	1125	565	794	174
Rush	Lot 28	1678	Stocker & Sitler	3 White	1150 RT	1210	633	834	146
Rush	Lot 31	1642	Stocker & Sitler	2 Long	965 RT	1042	436	670	222
Rush	Lot 31	1636	Stocker & Sitler	1 Long	1145 RT	1247	648	869	196
Rush	Sec. 2	1907	Phoenix	2 McCauley	962 KB	1008	499	630	26
Rush	Sec. 3	1618	Collins	2 Evans	914 KB	953	448	583	28
Rush	Sec. 14	1676	Stocker & Sitler	2 Edwards	1158 RT	1256	703	880	159
Rush	Sec. 15	1637	Stocker & Sitler	3 Long	1105 RT	1216	631	836	123
Rush	Sec. 15	1638	Stocker & Sitler	4 Long	988 RT	1124	539	744	176
Rush	Sec. 16	1664	Stocker & Sitler	1 Blackwell	1085 RT	1200	632	828	103
Rush	Sec. 16	1639	Stocker & Sitler	2 Kohl	913 RT	990	415	606	119
Rush	Sec. 16	1640	Stocker & Sitler	3 Kohl	912 RT	1074	504	692	137
Rush	Sec. 16	1641	Stocker & Sitler	4 Kohl	960 RT	1004	418	634	152
Rush	Sec. 17	1681	Stocker & Sitler	1 Ripley	925 RT	1034	460	657	151
Rush	Sec. 17	1682	Stocker & Sitler	2 Ripley	1183 RT	1291	711	975	242
Rush	Sec. 17	1683	Stocker & Sitler	3 Ripley	896 RT	1004	437	622	161
Rush	Sec. 17	1684	Stocker & Sitler	4 Ripley	898 RT	1002	411	672	201
Rush	Sec. 18	2045	Stocker & Sitler	1 Jones	810 RT	1009	454	636	92
Rush	Sec. 22	2327	Enterprise	1 Munro	920 DF	1052	473	681	146
Rush	Sec. 24	1693	Stocker & Sitler	1 Hines	1125 RT	1220	671	843	151
Rush	Sec. 24	1692	Stocker & Sitler	2 Hines	930 RT	1032	460	693	183
Rush	Sec. 24	1691	Stocker & Sitler	3 Hines	1210 RT	1294	708	913	192
Rush	Sec. 24	1690	Stocker & Sitler	4 Hines	1208 RT	1310	714	977	221
Rush	Sec. 25W	1667	Stocker & Sitler	2 Blackwell	1170 RT	1249	681	874	182
Rush	Sec. 25W	1666	Stocker & Sitler	3 Blackwell	1280 RT	1342	769	966	176
Rush	Sec. 25W	1665	Stocker & Sitler	4 Blackwell	1213 RT	1300	718	922	165
Rush	Sec. 25W	1030	Stocker & Sitler	2 Huebner	1221 KB	1284	720	916	126
Rush	Sec. 25E	1733	Resource	1 Poulson	879 KB	1042	506	684	45
Rush	Sec. 32	1735	Resource	1 Wright	867 DF	965	428	602	23
Salem	2Q	2024	Stocker & Sitler	1 Bender	890 RT	898	386	515	62
Salem	2Q	2077	Stocker & Sitler	2 Bender	1125 RT	1124	604	744	61
Salem	2Q	2087	Stocker & Sitler	3 Bender	885 RT	906	400	528	29
Salem	2Q	2097	Stocker & Sitler	4 Bender	865 RT	884	378	502	46
Salem	2Q	2004	Stocker & Sitler	2 Dichler	1210 RT	1213	761	835	14
Salem	2Q	2074	Stocker & Sitler	1 Fillman	828 RT	837	315	449	78
Salem	2Q	2075	Stocker & Sitler	2 Fillman	828 RT	849	299	463	75
Salem	2Q	2023	Stocker & Sitler	1 Larson	880 RT	855	314	484	169
Salem	2Q	2028	Stocker & Sitler	1 Schwab	1157 RT	1131	578	748	28
Salem	2Q	2027	Stocker & Sitler	2 Schwab	1227 RT	1198	641	811	115
Salem	2Q	2026	Stocker & Sitler	3 Schwab	940 RT	964	412	584	76
Salem	2Q	2025	Stocker & Sitler	4 Schwab	977 RT	968	412	590	67
Salem	2Q	2267	Enterprise	1 Spencer	875 DF	882	374	490	29
Salem	2Q	2073	Stocker & Sitler	1 Steinbach	827 RT	832	290	445	138
Salem	2Q	2070	Stocker & Sitler	2 Steinbach	828 RT	847	288	461	157

APPENDIX.—SUMMARY OF WELL-LOG DATA—Continued

Township	Land subdivision	Permit no.	Operator	Well no. and name	Reference elevation (ft above sea level)	Depth (ft) to top of Berea	Depth (ft) to top of "Big Injun"	Depth (ft) to base of "Big Injun"	Net thickness (ft) of "clean" "Big Injun"
TUSCARAWAS COUNTY (continued)									
Salem	Lot 25, 3Q	2105	Stocker & Sitler	1 Harris	820 RT	846	298	464	90
Salem	Lot 28, 3Q	1577	Northeast	1 Rosenberry	1164 RT	1218	644	852	108
Salem	Lot 8, 4Q	2148	Appalachian	1 Taylor-Baker	1059 KB	1123	663	751	77
Salem	Lot 9, 4Q	2112	Appalachian	1 Taylor	1029 KB	1113	654	740	48
Salem	Lot 18, Salem Tr.	2154	Enterprise	1 Dichler	837 DF	877	421	499	53
Salem	Sec. 1	2003	Stocker & Sitler	1 Dichler	1220 RT	1223	769	845	27
Salem	Sec. 1	2071	Stocker & Sitler	1 Mathias	1093 RT	1112	648	733	59
Salem	Sec. 1	2072	Stocker & Sitler	2 Mathias	1130 RT	1133	673	759	65
Salem	Sec. 2	2297	Caddo	1-B Lahmers	1027 KB	1001	550	630	3
Salem	Sec. 9	2010	Stocker & Sitler	1 Frank	1062 RT	1097	639	718	29
Salem	Sec. 9	2287	Caddo	1-A Lahmers	946 KB	971	514	600	42
Salem	Sec. 9	2313	Caddo	2-A Lahmers	1107 KB	1132	678E	759	17E
Salem	Sec. 9	2066	Caddo	1 Roth	922 KB	955	503	572	15
Salem	Sec. 10	2015	Stocker & Sitler	1 Kail	1051 RT	1078	622	699	36
Salem	Sec. 10	2012	Stocker & Sitler	2 Kail	930 RT	940	481	560	65
Salem	Sec. 11	2013	Stocker & Sitler	2 Wiand	937 RT	972	521	589	20
Salem	Sec. 12	2011	Stocker & Sitler	1 Wiand	862 RT	891	439	515	28
Salem	Sec. 13	1255	Western	1 Hinds	886 KB	914	458	546	25
Salem	Sec. 14	2354	Caddo	1 Russell	968 KB	1018	572	666	17
Salem	Sec. 18	2146	Appalachian	1 Huffman	920 KB	963	501	595	39
Salem	Sec. 24	2311	Caddo	1 Hogue	823 KB	886	431	526	42
Salem	Sec. 24	2067	Caddo	1 Meyers	865 KB	929	481	553	30
Warwick	2Q	1057	Cayman	1 Dessecker	897 KB	908	400	530	51
Warwick	2Q	1345	Appalachian	1 Fouts	980 KB	990	504	619	28
Warwick	2Q	1586	Appalachian	2 Fouts	1125 KB	1150	650	774	6
Warwick	2Q	1058	East Ohio	1 Hibbs	871 KB	888	396	508	84
Warwick	2Q	1084	East Ohio	1 Natoli	868 KB	876	398	497	78
Warwick	2Q	1103	Collins/Carter-Jones	1 Roth	866 DF	864	374	492	93
Warwick	2Q	1033	East Ohio	1 Schwark	905 KB	934	432	550	69
Warwick	3Q	1412	Stocker & Sitler	1 Conklin	863 RT	868	316	522	169
Warwick	3Q	1413	Stocker & Sitler	2 Conklin	909 RT	939	414	556	117
Warwick	3Q	1452	Collins	1 Evans	947 KB	975	507	603	34
Warwick	3Q	1430	Stocker & Sitler	1 Everett	845 RT	861	366	498	112
Warwick	3Q	1431	Stocker & Sitler	2 Everett	840 RT	868	333	498	96
Warwick	3Q	1432	Stocker & Sitler	3 Everett	860 RT	896	368	517	83
Warwick	3Q	1153	Collins	1 Hammersley	877 DF	877	387	497	91
Warwick	3Q	1268	Collins/Carter-Jones	1 Knisely	872 DF	882	418	503	73
Warwick	Lot 2, 4Q	1229	Collins/Carter-Jones	1 Baker	837 DF	852	368	480	94
Warwick	Lot 3, 4Q	1163	Collins/Carter-Jones	1 Everett	854 DF	871	386	520	102
Warwick	Lot 4, 4Q	1207	East Ohio	1 Johnson	948 KB	968	468	619	132
Warwick	Lot 5, 4Q	1206	East Ohio	1-A Johnson	954 KB	972	475	598	113
Warwick	Lot 8, 4Q	1132	Collins/Carter-Jones	1 Kinsey	921 DF	939	452	560	34
Warwick	Lot 9, 4Q	1146	Collins/Carter-Jones	1 Everett	952 DF	961	468	580	111
Warwick	Lot 11, 4Q	1167	Collins/Carter-Jones	1 Everett	842 DF	872	373	488	104
Warwick	Lot 14, 4Q	1284	Stocker & Sitler	2 Rank	974 KB	1025	462	662	141
Warwick	Lot 15, 4Q	1261	Stocker & Sitler	1 Rank	899 RT	948	430	576	145
Warwick	Lot 17, 4Q	1275	East Ohio	1 Reichman heirs	933 KB	970	467	587	86
Warwick	Lot 18, 4Q	1223	East Ohio	1 Lehr	916 KB	947	443	563	51
Warwick	Lot 22, 4Q	1212	East Ohio	1 Hostetler	930 KB	972	454	597	136
Warwick	Sec. 1	1032	East Ohio	1 Berlandis	1062 KB	1067	557	682	113
Warwick	Sec. 2	2103	Tipka	1 Gundy	993 RT	965	422	577	72
Warwick	Sec. 10	1048	East Ohio	1 Cross Creek Coal	972 DF	993	520	627	90
Warwick	Sec. 10	1020	Quaker State	1 Simmons	1223 KB	1219	728	840	77
Warwick	Sec. 11	1148	East Ohio	1 Everett	935 KB	954	446	576	125
Warwick	Sec. 11	1323	East Ohio	1 Lichti	934 KB	952	444	575	81
Warwick	Sec. 11	1324	East Ohio	1 Rummell	868 KB	882	382	512	73
Warwick	Sec. 12	2133	Blaze	2 Everett	1126 KB	1130	622	748	66
Washington	Lot 1, 1Q	1393	Stocker & Sitler	3 Holtz	1225 RT	1317	747	979	217
Washington	Lot 2, 1Q	1392	Stocker & Sitler	2 Holtz	1150 RT	1234	673	862	172
Washington	Lot 4, 1Q	1390	Stocker & Sitler	1 Holtz	1259 RT	1330	768	953	149
Washington	Lot 5, 1Q	1621	Stocker & Sitler	4 Morrison	1120 RT	1187	614	835	198
Washington	Lot 6, 1Q	1622	Stocker & Sitler	3 Morrison	1268 RT	1319	769	941	134

APPENDIX.—SUMMARY OF WELL-LOG DATA—Continued

Township	Land subdivision	Permit no.	Operator	Well no. and name	Reference elevation (ft above sea level)	Depth (ft) to top of Berea	Depth (ft) to top of "Big Injun"	Depth (ft) to base of "Big Injun"	Net thickness (ft) of "clean" "Big Injun"
TUSCARAWAS COUNTY (continued)									
Washington	Lot 8, 1Q	1584	Stocker & Sitler	1 Morrison	1200 RT	1244	656	880	205
Washington	Lot 9, 1Q	1417	Stocker & Sitler	1 Hursey	1079 RT	1123	551	752	179
Washington	Lot 11, 1Q	1419	Stocker & Sitler	3 Hursey	1255 RT	1295	718	917	175
Washington	Lot 12, 1Q	1420	Stocker & Sitler	4 Hursey	1179 RT	1245	680	862	162
Washington	Lot 13, 1Q	1446	Stocker & Sitler	1 Helter	1109 RT	1200	624	826	174
Washington	Lot 14, 1Q	1448	Stocker & Sitler	3 Helter	1100 RT	1187	649	850	144
Washington	Lot 17, 1Q	1449	Stocker & Sitler	4 Helter	1105 RT	1209	688	834	80
Washington	Lot 18, 1Q	1388	Tri-State	1 Hursey	891 KB	989	NL	633	127+
Washington	Lot 20, 1Q	1447	Stocker & Sitler	2 Helter	1099 RT	1185	620	805	175
Washington	Lot 23, 1Q	1418	Stocker & Sitler	2 Hursey	1135 RT	1192	631	804	107
Washington	Lot 25, 1Q	1322	Stocker & Sitler	1 Gardner	1139 RT	1177	608	808	131
Washington	Lot 26, 1Q	1298	Stocker & Sitler	1 Cappel	1110 KB	1165	565	791	187
Washington	Lot 31, 1Q	1582	Northeast	1 Berger	1096 KB	1182	582	794	86
Washington	Lot 34, 1Q	1387	Tri-State	1 Taylor	903 KB	985	NL	608	34+
Washington	Lot 40, 1Q	2123	Enterprise	1 Tedrow	1105 RT	1173	612	794	127
Washington	Lot 41, 1Q	1355	Lenhart & Bennett	1 Cappel	906 KB	966	352	588	175
Washington	Lot 4, 2Q	1353	Collins/Carter-Jones	1 Hunt	1087 DF	1161	568	777	138
Washington	Lot 16, 2Q	1675	Lenhart & Bennett	2-S Bond	860 DF	902	NL	523	14+
Washington	Sec. 11	1391	Stocker & Sitler	4 Holtz	1149 RT	1295	723	962	226
Washington	Sec. 11	1385	Tri-State	1 Howe	1163 RT	1281	757	935	177
Washington	Sec. 12	1386	Tri-State	1 Hursey	893 RT	1007	473	629	145
Washington	Sec. 20	2108	Enterprise	1 Dunlap	1160 RT	1276	693	929	216
Washington	Sec. 20	2266	Enterprise	1 Nay	925 RT	1027	484	665	175

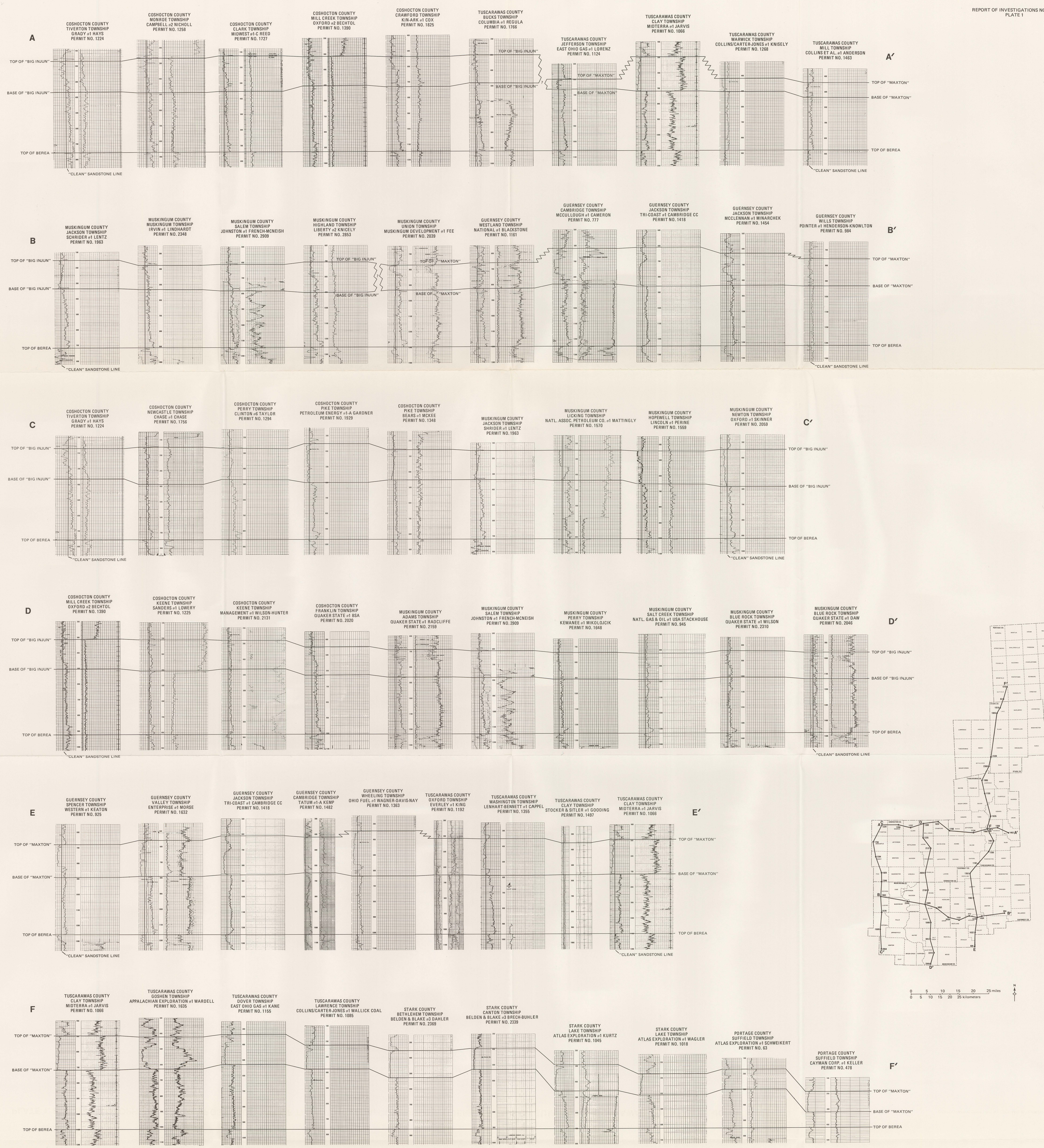


PLATE 1. BOREHOLE GEOPHYSICAL-LOG CROSS SECTIONS OF THE STUDY AREA, COSHOCTON, GUERNSEY, MUSKINGUM, AND TUSCARAWAS COUNTIES, OHIO

CARTOGRAPHIC DRAFTING BY LEONARD M. GUCKENHEIMER

PLATE 2. ISOPACH MAP OF "CLEAN" SANDSTONE, DRILLERS' "BIG INJUN" ("BIG INJUN" AND "MAXTON")

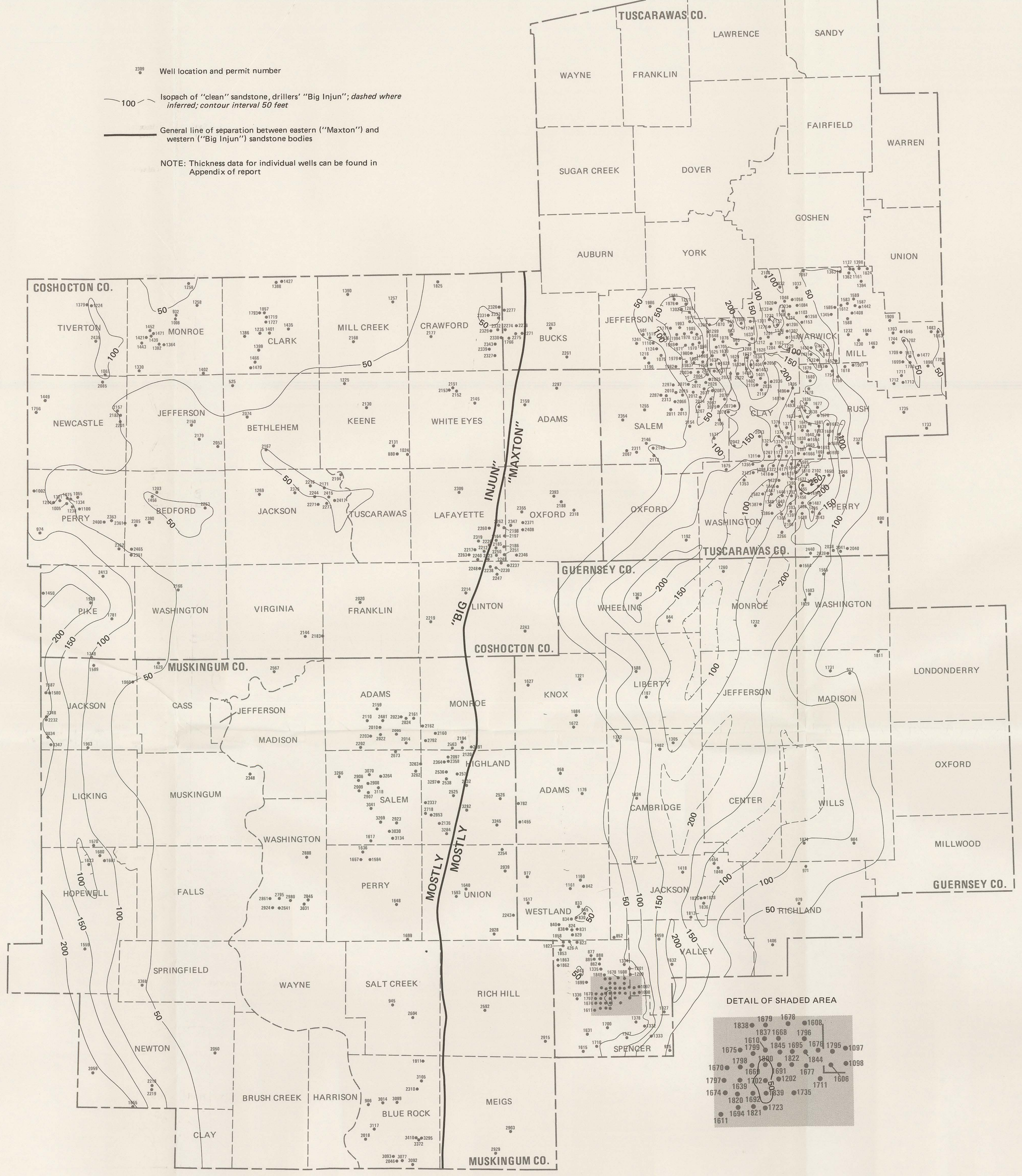


PLATE 3. ISOCHORE MAP OF THE STRATIGRAPHIC INTERVAL FROM THE BASE OF THE "BIG INJUN" OR "MAXTON" TO THE TOP OF THE BEREA SANDSTONE

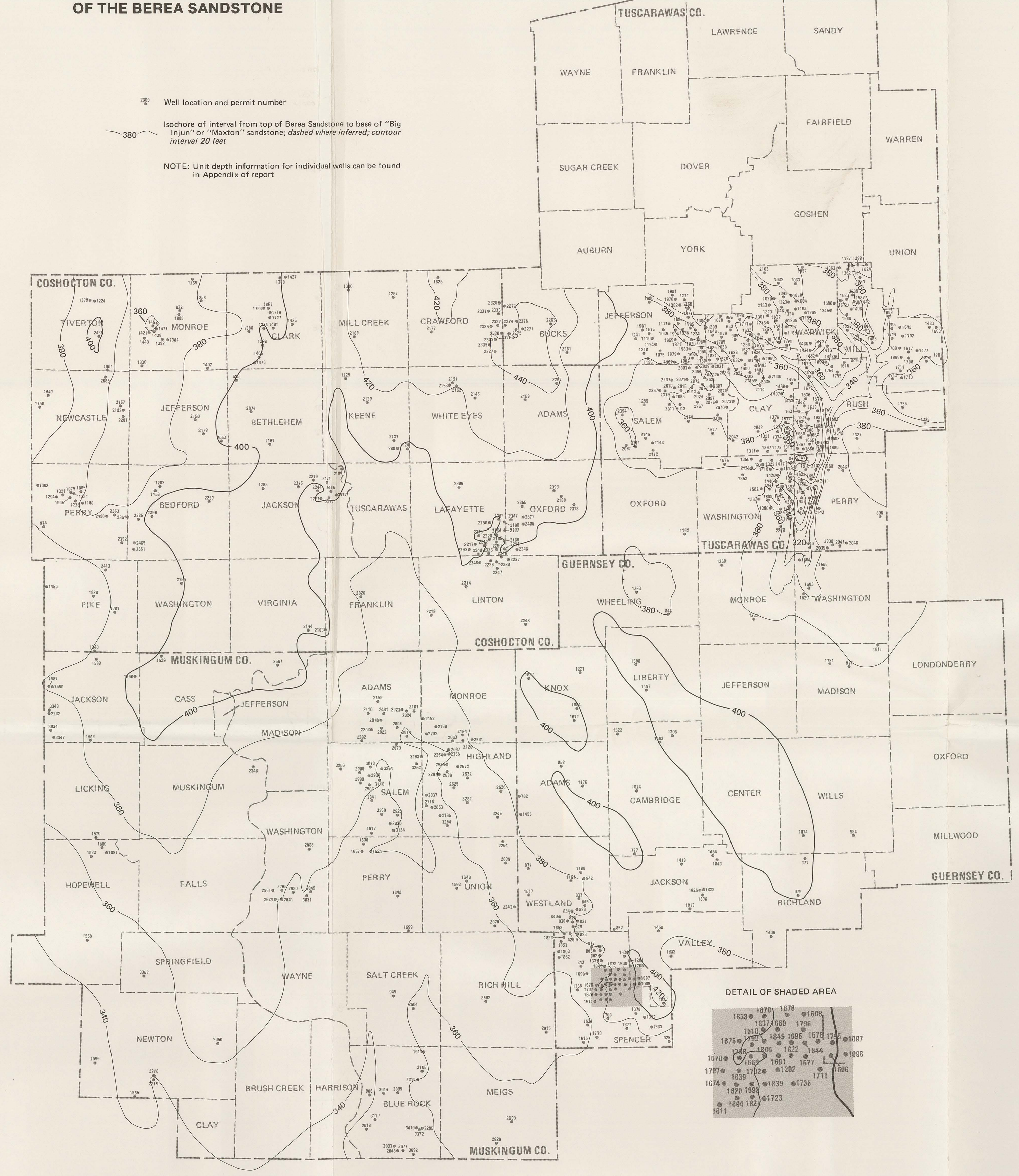


PLATE 4. GENERALIZED STRUCTURE CONTOUR MAP OF THE TOP OF THE BEREA SANDSTONE

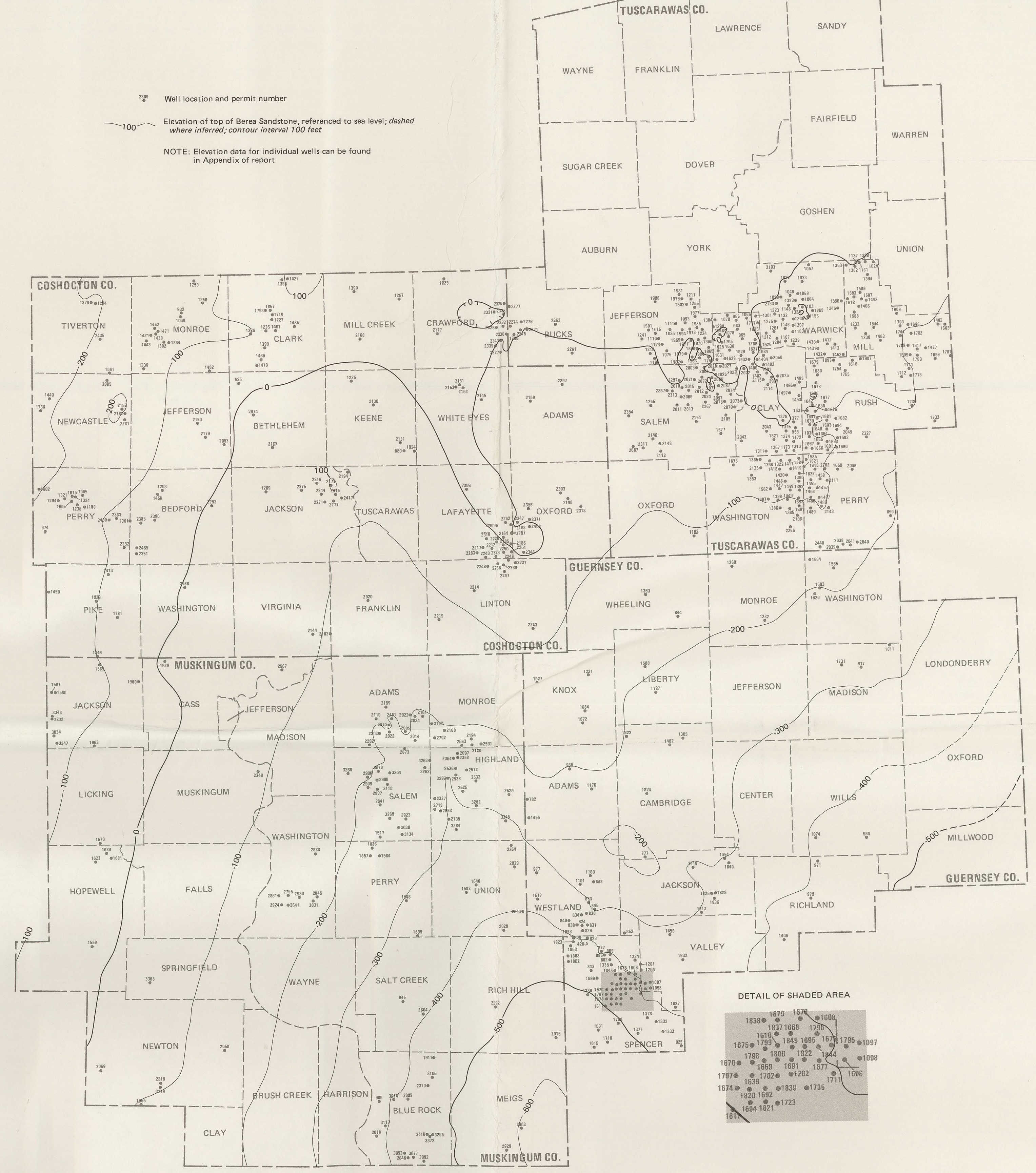
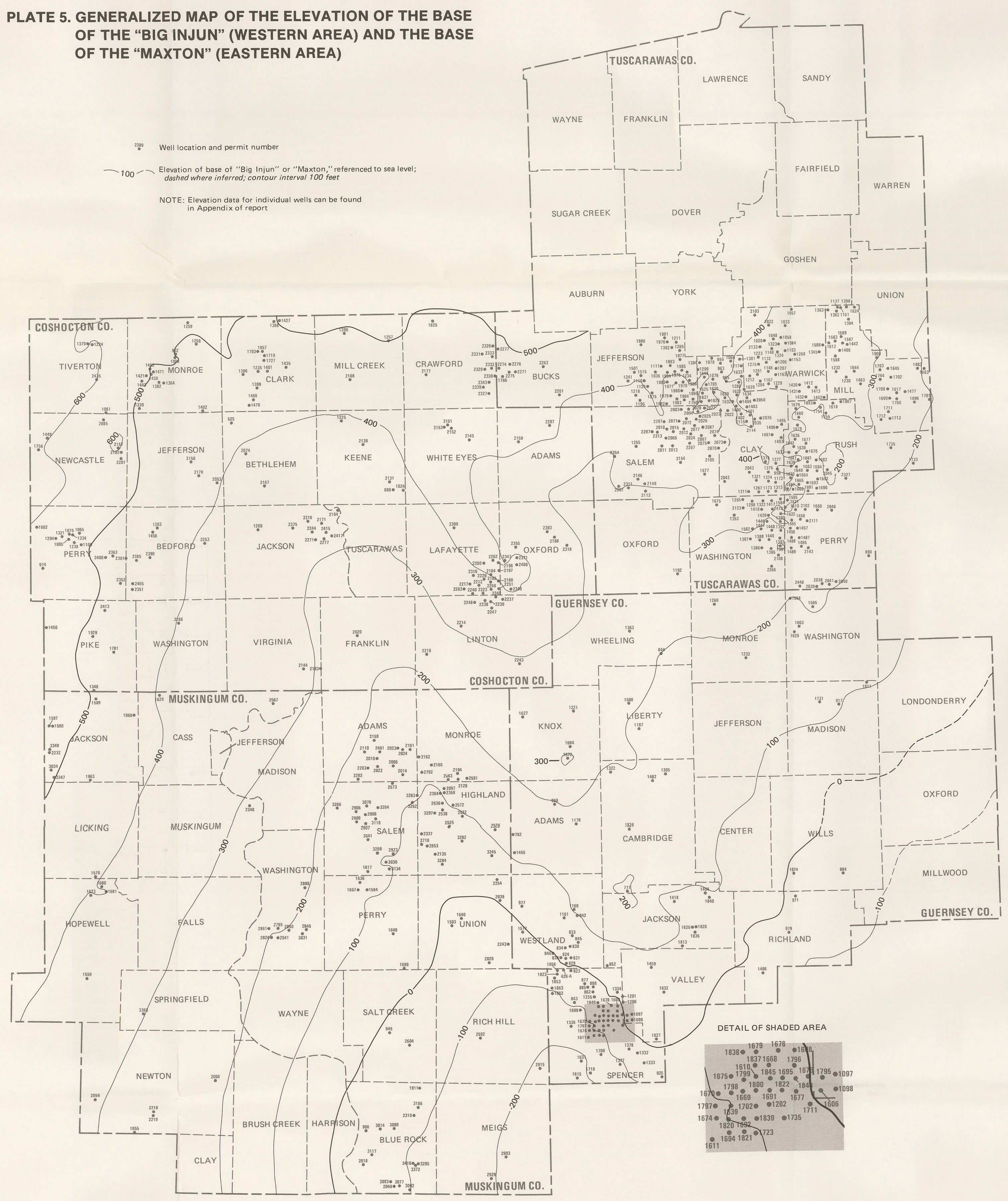
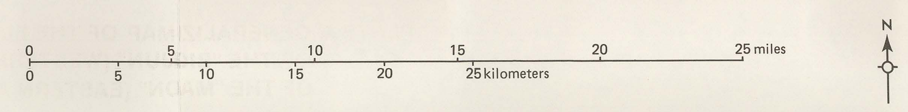


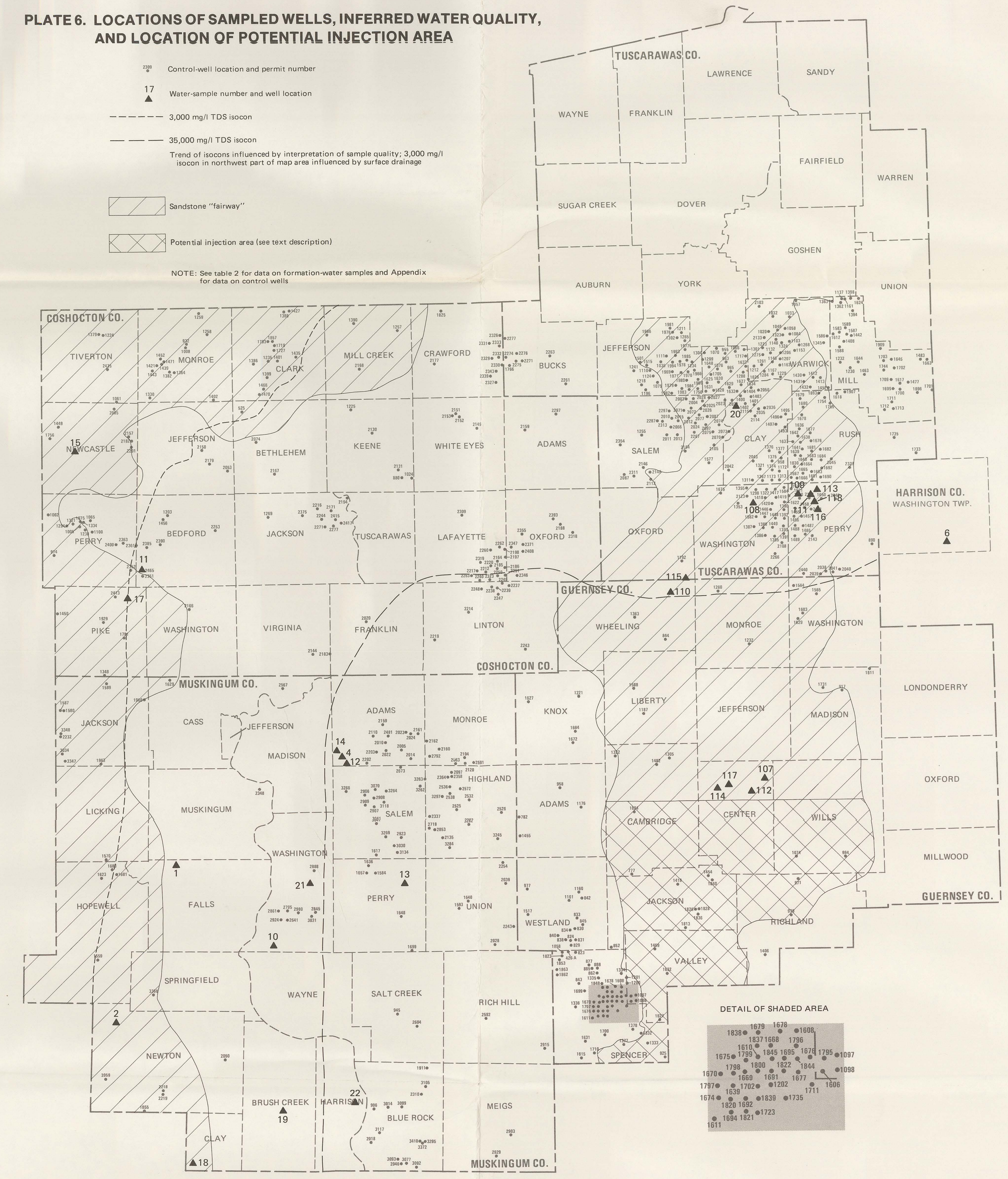
PLATE 5. GENERALIZED MAP OF THE ELEVATION OF THE BASE OF THE "BIG INJUN" (WESTERN AREA) AND THE BASE OF THE "MAXTON" (EASTERN AREA)





LOCATION MAP

PLATE 6. LOCATIONS OF SAMPLED WELLS, INFERRED WATER QUALITY, AND LOCATION OF POTENTIAL INJECTION AREA



CARTOGRAPHIC DRAFTING BY LEONARD M. GUCKENHEIMER